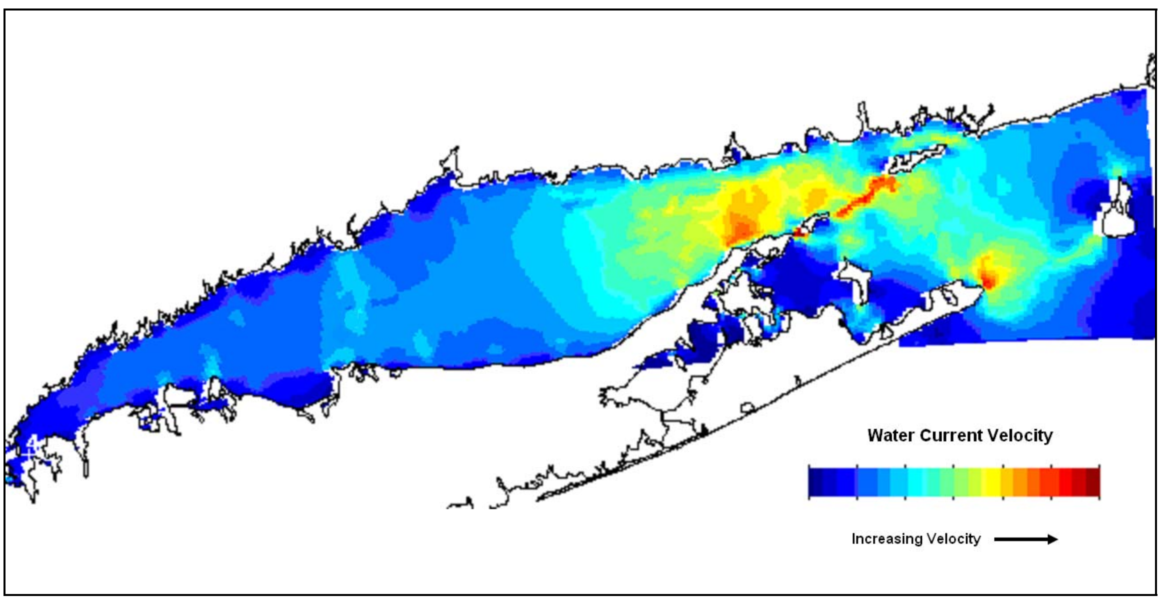
Long Island
Tidal and Wave Energy Study:
An Assessment of the Resource

January 2007

Prepared for:
Long Island Power Authority

Prepared by:
E3, Inc.



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Citations

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Executive Summary

The scope of this study is to (1) clarify the potential development of Tidal In-Stream Energy Conversion (TISEC) and Wave Energy Conversion (WEC) systems as they relate to marine resources in the LIPA service territory, (2) evaluate possible technologies that might effectively operate in these waterways to generate electric power, and (3) introduce an evaluation of related regulations, potential environmental impacts, marine safety and available transmission lines issues that may affect such resource development and siting.

It is expected that our energy future will require a fundamental change from our energy past. Our present time is faced with critical choices regarding energy use and technology development that may significantly impact our future quality of life. Our generation bears witness to the pressures of climate change, planetary stewardship and the problem of peak oil production. These forces will in all likelihood introduce an era of energy transformation with a probable strong element of power generation from renewable sources.

Within the context of these energy challenges, the promise of a variety of Renewable Energy (RE) opportunities may provide possible simultaneous solutions of regional economic stimulus, pollution free energy production and greater regional security through the development of indigenous resources. RE development is further advanced by LIPA's Clean Energy Initiative and Renewable Portfolio Standards (RPS), which require increased renewable electricity generation during the next 20 years in 22 states and the District of Columbia. New York State has a goal of 25% of its electricity coming from renewable resources by 2013, i.e., in seven years. [4]

In light of these pressures for change and promising opportunities that are unique to our time and region, LIPA has initiated this resource and technology study. The development of marine energy systems to produce electric power is in its infancy. As such, it is important to describe and differentiate the terms as used in this report and to clarify what precisely is being studied and why. There are essentially six applications of marine-related technologies: Ocean Energy Technology, In-Stream Hydroelectric Technology, Ocean Thermal Energy Conversion (OTEC), Tidal Barrage Systems, Tidal In-Stream Energy Conversion (TISEC) and Wave Energy Conversion (WEC). The four following technologies are not evaluated in this study include:

- Ocean Energy Technology which generally refers to power derived from the flow of ocean currents. The velocities of most ocean currents are too slow to effectively generate electric power from most known existing technologies.
- In-Stream Hydroelectric Technology which is used in rivers and streams does not constitute a major regional resource.
- OTEC (Ocean Thermal Energy Conversion) Systems produce power from thermal gradients or temperature differences in offshore waterways and have never proven to be remotely economically viable.
- Tidal Barrage Systems are operative in four nations around the world but are viewed by a broad consensus as highly destructive to regional environments and are highly unlikely to be permitted in New York State.

The technologies presented in this study include:

- TISEC (Tidal In-Stream Energy Conversion) Systems can produce electric power from regional resources using existing technologies, or those currently under development, given measured water speeds in Long Island's offshore waterways.
- WEC (Wave Energy Conversion) Systems produce electric power from the oscillations and impact of waves. Most leading edge WEC technology developers agree that Long Island wave conditions present borderline opportunities for existing technologies, at best. Future technology development or climate change impacts on wave intensity may provide more favorable opportunities for WEC system deployment in Long Island waterways.

This study of potential energy generation from tidal and wave energy technologies is presented during a time when policy changes and priorities are currently undergoing potentially significant change, review and adjustment. The current policies are presented within the existing regulatory framework and identify some of the issues of key environmental concern. A realistic evaluation of the LIPA transmission lines that may require upgrades to deliver grid connected ocean energy must be assessed. Navigational safety issues and concerns over possible impacts to marine ecosystems are also presented.

In general terms, the wave energy potential off the coast of the U.S. is significant. Harnessing just 20% of the available wave energy resource base (2,300 TWh/yr) at 50% conversion efficiency would generate as much electricity as all of the conventional hydropower currently installed in the United States (270 TWh/yr). The wave energy resource of Maine, New Hampshire, Massachusetts, Rhode Island, New York, and New Jersey is vital, estimated at 110 TWh/yr[1]. A British government study presented to the House of Commons in 1999 stated that "if less than 0.1% of the energy in the world's oceans were converted into electricity, it would supply the world energy demand 5 times over."[2]

Tidal power presents development opportunities in Long Island's waterways. Every day, year in and year out, a constant, predictable pulse of power consisting of un-utilized tidal energy moves across the 137-mile span of ocean intersected by Long Island, comprising a shoreline of almost 1,000 miles of linear coast. This energy resource provides a diurnal pattern representing four tidal peaks every 24 hours and 50 minutes that follow the daily pattern of lunar movement. This includes two Ebb Tide cycles generally moving easterly, and two Flood cycles generally moving westerly. The pace of tidal energy technology advance presents an opportunity to supply a significant portion of the RPS requirements while also providing a significant economic stimulus for marine services through the production of clean, renewable energy.

Primary siting issues concerning tidal power development include the speed, duration and depth of tidal water currents, characteristics of bottom sediments and rock formation, evaluating factors such as navigation patterns and safety, assessing shoreline impacts and possible effects on marine ecology and sea life.

Issues that impact potential site selection of wave power technology are similar, although a critical difference includes an understanding of the prevailing historical and predictive wave environment. This includes an understanding of average annual heights, the potential power in the waves (expressed as kW per linear meter of wave front), prevailing directions of wave movements and a clear analysis of 20-year wave heights based on predictive models and hind-casts derived from analysis of detailed historical data.

The extractable tidal power from The Race at the eastern end of Long Island Sound alone is estimated between 400 to 500 MW using a small fraction of the total energy available.(calculations presented on page 53 and 54 of this document)Additional tidal power available from tidal currents racing through the shoreline inlets that ring the Long Island coast may total as much as 100 additional MW also using just a similar fraction of the potential ocean kinetic power.

This Report provides the following information in each of the numbered sections and includes; (1) a review of tidal and wave resource basics, (2) a detailed evaluation of potential tidal and wave energy site opportunities, (3) summary status of tidal and wave energy technology, (4) overview of key regulatory, environmental, interconnection, and marine safety issues, and (5) conclusions and recommendations.

While the abundant marine resources and the strong offshore currents of Long Island offer much promise in a future mix of clean, renewable energy; the impacted communities, interest groups, energy companies and other stakeholders would be well served to use this and other references to evaluate the potential opportunities and pitfalls such a future might bring to the region. Along with the opportunities for economic revitalization and power generation that promote improved energy security and greater energy independence, comes the balancing need for wise stewardship of those very same resources. The on-going dialogue concerning this balance will be best served by the development of detailed and factual data, site-specific analyses, and an objective investigation supported by an informed discussion.

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1. Introduction

1.1 Scope of this Study

The scope of this study is to (1) clarify the potential development of Tidal In-Stream Energy Conversion (TISEC) and Wave Energy Conversion (WEC) systems as they relate to ocean, sound and bay resources in the LIPA service territory, (2) evaluate possible technologies that might effectively operate in these waterways to generate electric power, and (3) introduce an evaluation of regulations, available transmission lines, marine safety, and environmental impact.

Recent regulatory developments are discussed with the understanding that policy changes and priorities may require review and adjustment as climate change impacts and the challenges of peak oil collide. Most experts agree that we are currently at or nearly at the point of peak oil production that will foster a major economic and technology transition. We are clearly in the early stages of an era of energy transformation that is driving greater interest in energy alternatives. These alternatives promise the possible combined benefits of regional economic stimulus, improved environmental health and greater domestic energy security.

1.2 Background

Marine energy systems in this analysis include technology that either extracts power from the movements of (1) tidal currents or from the (2) wave action, both of which move mechanical elements that are converted to electrical power. Primary siting issues concerning tidal power development include the speed, duration and depth of tidal water currents, bottom sediments and bedrock, evaluating factors such as navigation patterns and safety, shoreline impacts and possible effects on marine ecology and sea life.

Issues that impact potential site selection of wave power technology are similar, but a critical difference includes an understanding of the prevailing, historical and predictive wave environment. This includes an understanding of average annual heights, the potential power in the waves (expressed as kW per linear meter of wave front), prevailing directions of wave movements, and a clear analysis of 20 year wave heights based on predictive models and hind-casts derived from analysis of detailed historical data. These data are presented in general terms later in this chapter and in greater detail in Sections 2 and 3.

There are essentially six applications of marine-related technologies: Ocean Energy Technology, In-Stream Hydroelectric Technology, Ocean Thermal Energy Conversion (OTEC), Tidal Barrage Systems, Tidal In-Stream Energy Conversion (TISEC) and Wave Energy Conversion (WEC). The four following technologies are not evaluated in this study due to the following reasons:

- Ocean Energy Technology generally refers to power derived from the flow of ocean currents. The velocities of most ocean currents are too slow to effectively generate electric power.
- In-Stream Hydroelectric Technology used in rivers and streams do not constitute a major regional resource.
- OTEC (Ocean Thermal Energy Conversion) Systems use the temperature differential between surface waters and deep ocean waters to drive a turbine to produce electricity and have never proven to be remotely economically viable. Such a system has been operative on the Kona Coast of Hawaii for several decades and has never produced significant electricity.
- Tidal Barrage Systems are operative in four nations around the world but are viewed by a broad consensus as highly destructive to regional environments. This system has been extensively discussed in the literature of tidal power. Tidal barrages act much like a conventional dam that provides a hydropower solution for power generation. Barrages dam a tidal inlet or passage and allow water to flow through tidal gates until high tide is reached. At this point the gates are closed until low tide. The gates have now captured the “head” or height of the high tide water and then provide for power generation using conventional hydro turbines that produce electric power from the action of gravity impact on flowing water out of the dammed waterway. Four such systems have been constructed in the world to date including an initial 240

MW system in La Rance, France. However, due to the blockage of critical water flows in inter-tidal areas, such systems are unlikely to be permitted in New York State due to the resultant negative environmental impacts.

The focus of the study includes:

- TISEC (Tidal In-Stream Energy Conversion) Systems that are sufficient to produce electric power with existing technologies, or those currently under development, given measured water speeds in Long Island's offshore waterways; and
- WEC (Wave Energy Conversion) Systems that produce electric power from the oscillations and impact of waves. Most leading edge WEC technology developers agree that Long Island wave conditions present borderline opportunities for existing technologies. Future technology development or climate change impacts on wave intensity may provide more favorable opportunities for WEC system deployment in Long Island waterways.

Useful power was extracted from tides almost 400 years ago on Long Island and tidal power mills date back 1,000 years in England. Historical sites on Long Island were near shore applications that served the immediate needs of mechanical milling of important grains.

1.3 Understanding Marine Resources

The world's oceans are a powerful and untapped energy resource for both TISEC and WEC systems. They cover two-thirds of the earth's surface, representing a potentially huge, clean energy source. It is estimated that if less than 0.1% of the renewable energy within the oceans could be converted into electricity, it would satisfy the present world demand for energy more than five times over.[2]

Tidal Energy may offer promise for supporting LIPA's electric power production goals and the Renewable Portfolio Standard (RPS) mandated by the New York State Public Service Commission. Tapping and harvesting natural energy flows require no fuels and produce no pollution. For a region such as Long Island which is highly dependent on imported energy sources, the focused and successful development of these systems could provide multiple benefits.

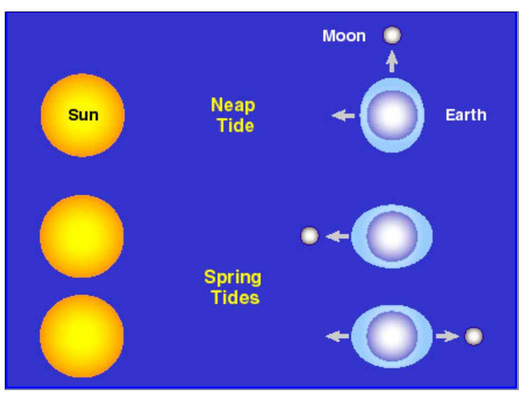
1.4 Tidal Energy Resources

The power density of water is approximately 1,000 times that of air. In comparison with the renewable wind energy resource, more electric power can be generated using less material due to this energy density difference. Based on the highly successful development of worldwide wind energy during the past several decades, with appropriate technology investment, wave and tidal power offers a promising future. Factors that support this view include:

- Large off shore and near shore areas with energy production potential,
- High level of predictability of tidal processes,
- Very accurate repeatability of tides, and
- Significant interfaces between key tidal flows and grid connections.

The Moon is the dominant factor controlling period and height of tides. The Sun's great mass, however, causes an appreciable effect – an average solar tide height is about half the average lunar tide. At the time when both Moon and Sun are positioned such that their gravitational forces are aligned (New Moon and Full Moon), we observe the so-called spring tides, in contrast with neap tides, when gravitational forces are opposed (Figure 1.1).

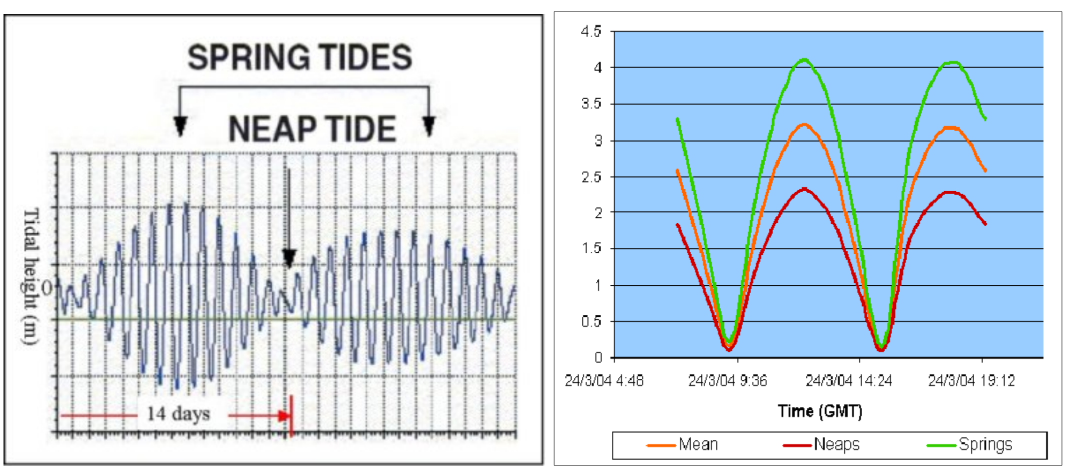
Figure 1.1 - Position of the Sun and Moon to Create Neap and Spring Tides.



Spring tides present the very highest and very lowest tide (i.e. the largest tidal range), which occurs twice a month (every 14/15 days). Neap tides present a tidal range when high and low water is smallest and occurs nearest the time of the first and last lunar quarters. The spring/neap ratio can be as much as 2 to 1.

The combination of the spring to neap cycle and the 14-day diurnal tidal cycle results in a variability of the tides through the months of the year. There are more than a hundred harmonic constituents (cyclic components) of the tide, each with a different cycle time. These factors combine so that tides only completely repeat themselves every 18.6 years[3]. A key point is the high level of predictability of tides, in spite of the apparent complexity described by this pattern.

Figure 1.2 - Comparison of Spring and Neap Tides



The following figures present an overview of Tidal In-Stream Energy Conversion (TISEC) Resource Basics (Fig. 1.3), Global Distribution of Tidal Range (Fig. 1.4), and Major North American Tidal Current Resources (Fig. 1.5). **Figure 1.3 Tidal In-Stream Energy Conversion** presents basic information about the generation of the tides from primarily lunar forces and explains the fact that the tide change occurs 50 minutes later each day due to the relative positions of the earth and moon. **Figure 1.4 Global Distribution of Tidal Range** presents a chromatic representation of the range of tidal height in its global distribution. This factor is not as significant as tidal water speed which is not directly related to tidal height. The technologies assessed in this report operate most effectively in specific speeds of tidal currents. **Figure 1.5 Major North American Tidal Current Resources** identifies areas along the US coastlines that are subject to tidal flows for potential energy generation. A resource not included in this depiction is power generation using similar TISEC technology in flowing waterways such as rivers, and industrial flows that include canals, Waste Water Treatment Plants (WWTPs), mine water discharges, and other industrial sources of flowing waterways.

Figure 1.3 Tidal In-Stream Energy Conversion (EPRI)

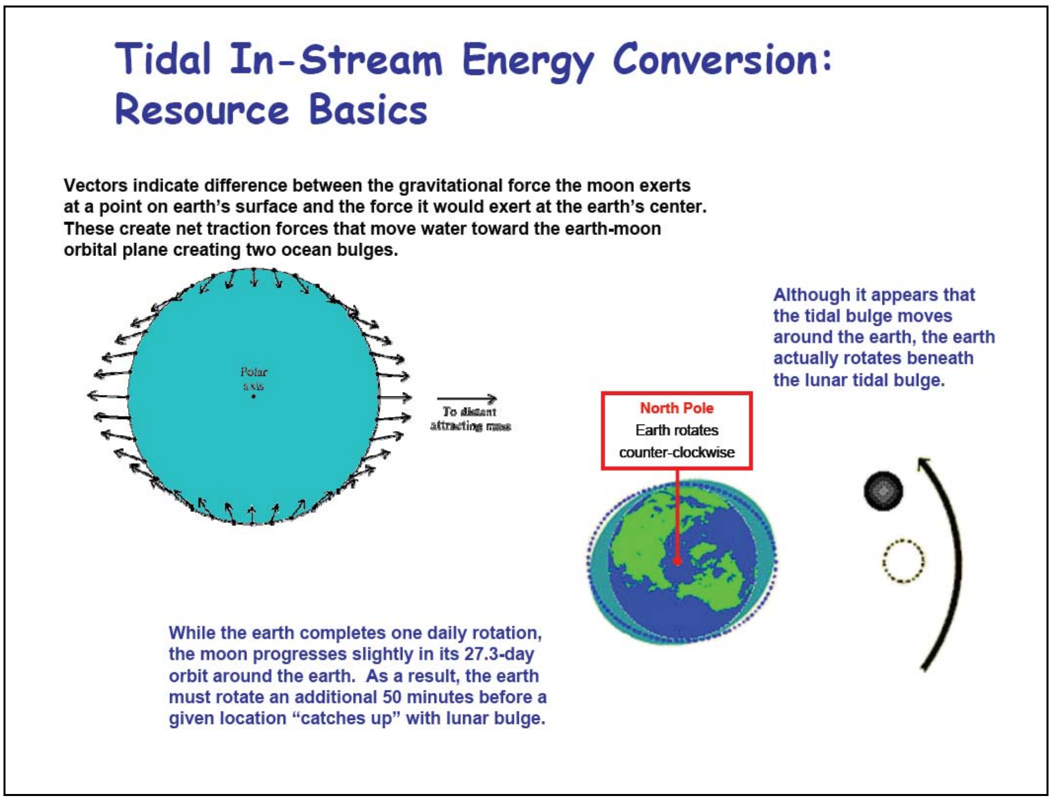


Figure 1.4 Global Distribution of Tidal Range (EPRI)

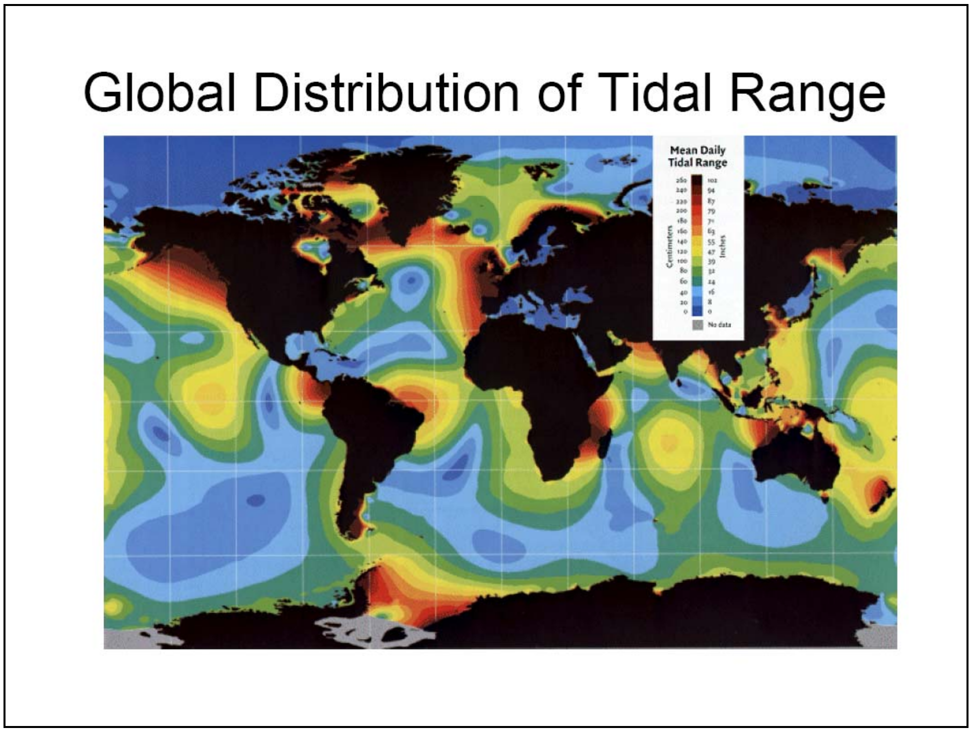
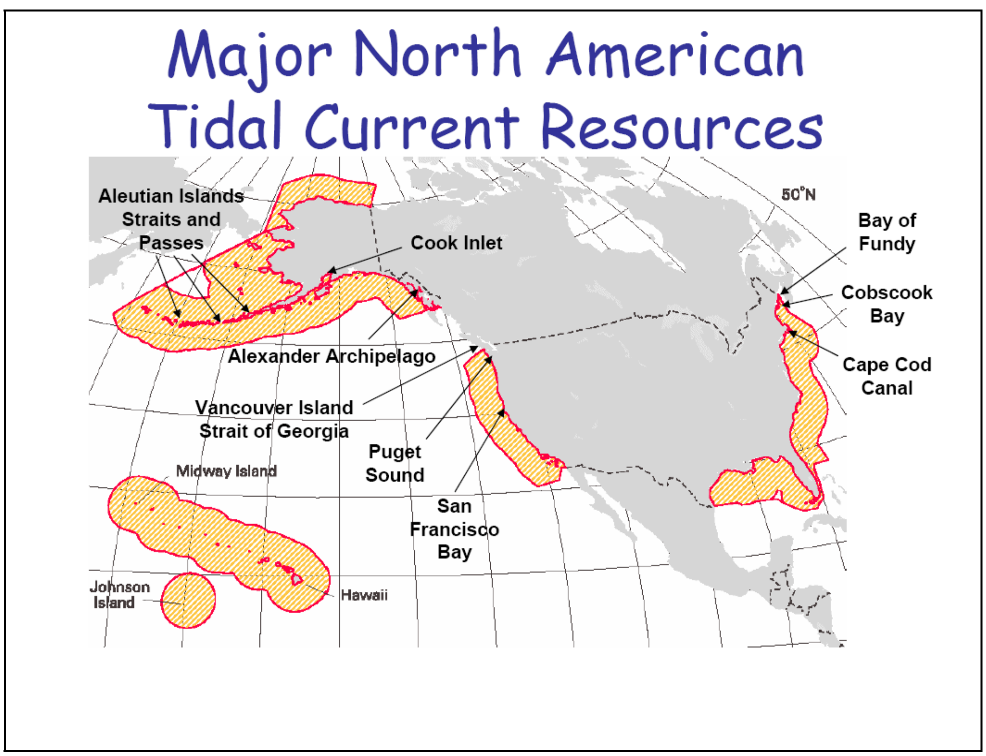


Figure 1.5 - US Tidal Current Resources (EPRI)



1.5 Wave Energy Resources

Wave energy presents a large potential for electric power generation. Specific conditions vary, however, and not all regions have equal potential for prime wave energy generation sites. **Figure 1.6 Resource Basics for Wave Energy Conversion** provides basic information about how waves are generated from the fetch or run of the wind over an extended waterway. Generally speaking, the winds in the northern temperate zones move from west to east. For this reason the west coast of North America and Europe provide the highest potential for cost effective wave energy generation as presented in **Figure 1.7 Wave Energy Global Resource Distribution.**

Figure 1.8 US Economic Zones for Potential Wave Energy presents an overview of areas with the greatest potential for wave energy generation. Most coastal areas in the US have some potential for wave energy generation with the exception of the Central and Southern areas of the East Coast and the Gulf of Mexico. The areas in and around New York and Long Island are considered borderline where the energy density in the annual wave generation lacks sufficient power to be considered a primary area for significant wave energy projects.

Figure 1.6 Resource Basics for Wave Energy Conversion (EPRI)

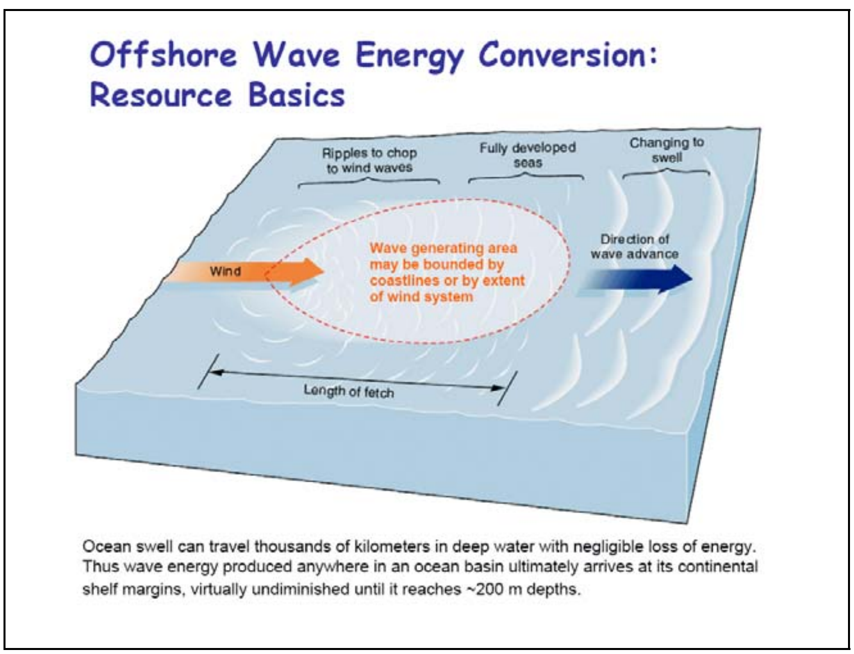


Figure 1.7 - Wave Energy Global Resource Distribution (EPRI)

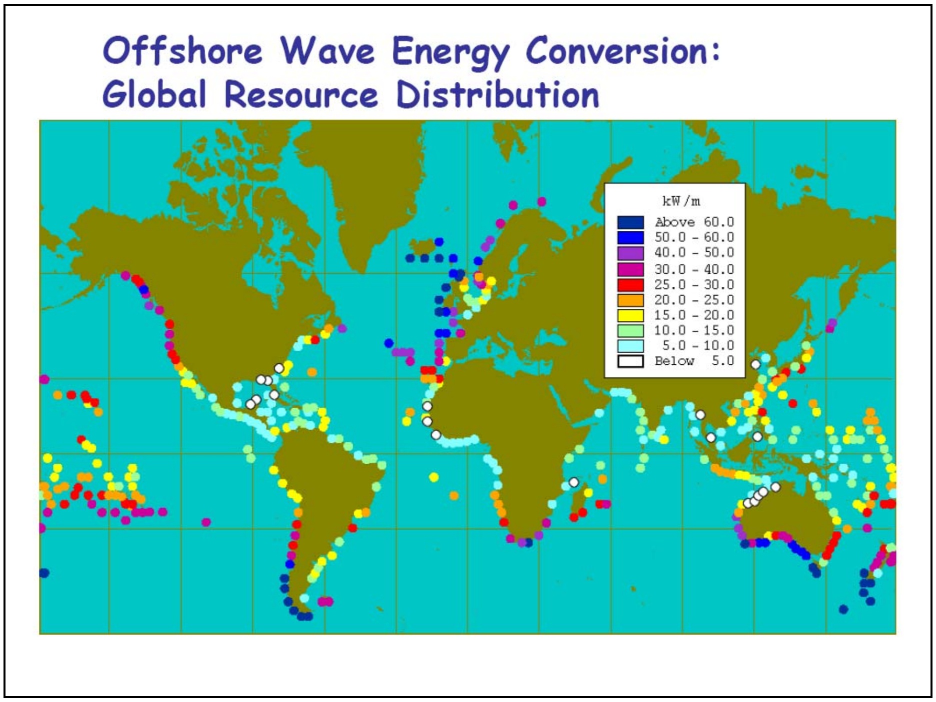
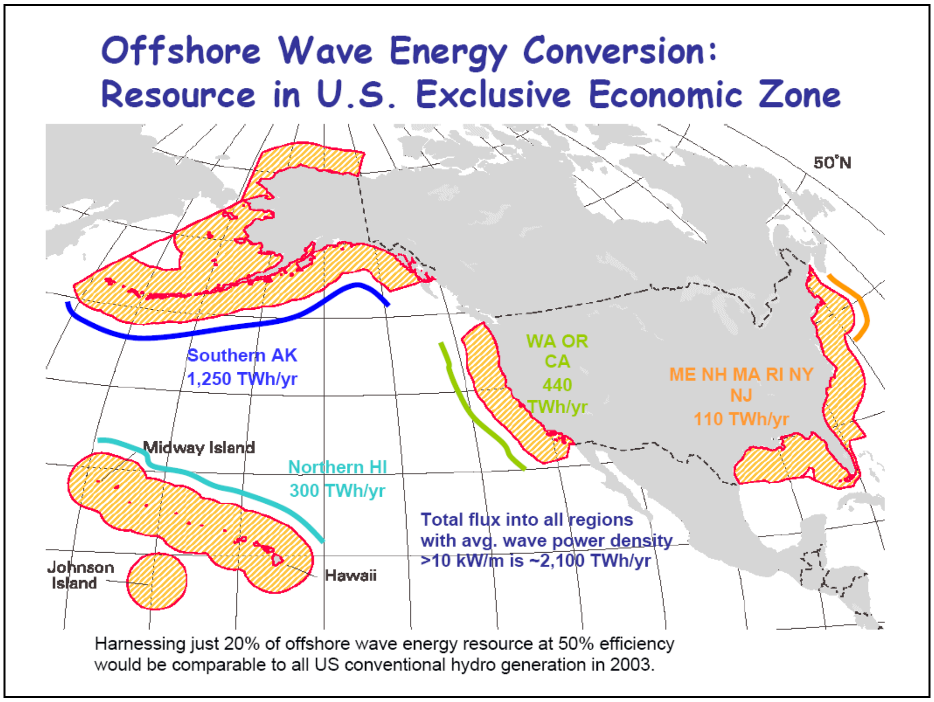


Figure 1.8 US Economic Zones for Potential Wave Energy (EPRI)



2. LIPA Marine Energy Resources

2.1 Potential Tidal Power Sites

A complex evaluation was performed by E3, Inc. staff to determine the potential for power at over 483 prospective tidal sites off the shorelines of Long Island, New York, Rhode Island, and New Jersey based on information available at NOAA data collection sites and extrapolated values. Of these sites, approximately twenty (20) mapped priority locations have been identified and are presented in the following maps of Long Island.

These sites are identified in **Table 2.1** which presents a site number, site name, latitude and longitude, maximum water speed in knots (1 knot = 0.5 meters per second), and water depth in feet.

Figure 2.1 Locations with Strong Tidal Currents around Long Island provides a spatial presentation of data presented in Table 2.1. This information is disaggregated in **Figure 2.2 - Sites With Depth < 50 ft, Long Island** and **Figure 2.3 - Sites With Depth > 50 ft, Long Island** due to the fact that depth variables may significantly impact deployment strategies for bottom-mounted pylon systems and may impact navigational issues.

Figure 2.4 Historical Tidal Sites - Long Island, NY (Operational 1644 to 1990) and **Figure 2.5 Hydro/Mill Resources - Long Island, NY (Operational 1698 to 1900)** provides the results of research into the historical past of tidal mills and watermills operational in the past eras of mechanical conversion of water flows for primarily mechanical milling functions. Figures 2.4 and 2.5 provide historical background information. This information may be of interest for potential future development of small-scale hydro projects. Additional information is presented in **Figure 2.6 Preliminary Wave Energy Resource on Long Island, NY** and **Figure 2.7 Hydro Tidal and Wave Resources on Long Island, NY** which presents a summary of all data in figures 1-6. Additional sites may be available in off shore areas as micro currents or small localized water flows that may provide opportunities to capture flowing waterways, particularly for off-grid applications.

Approximatlely 20 potential tidal power sites have been identified in waters near the LIPA service territory that could be considered for power production. Some of these locations may not be good candidates for various reasons. Of these sites, The Race at the eastern end of Long Island is one of the largest and fastest waterways in the world. It may provide power generation on the order of 400-500 MW.

The total potential power generation for tidal power in Long Island inlets not including The Race may total as much as 100 MW. The total potential power generation for tidal power in and around Long Island is estimated at about 500 MW using a small fraction of the total energy available. Based on recent data concerning LIPA power generation, approximately 90% of LIPA power generation is from oil and natural gas and is equivalent to about 4,821 MW from these sources. [10] It can thus be estimated that about 10% of the power generation from oil and natural gas could theoretically be replaced with tidal power generation. At an estimated cost of $2.5 Million/MW, replacement of 500 MW of generation with tidal power generation would result in a cost of $1.25 billion and would include the costs associated with upgrading the LIPA transmission and distribution system to handle this increased capacity.

Table 2.1 Locations with Strong Tidal Currents around Long Island

Site #	Latitude	Longitude	Site Name	Currents ID	Tides ID	Max Water Speed (Knots)	Water Depth (ft)
01	40.9666667	-73.1000000	Port Jefferson Harbor Entrance	3106	1377	4.49	10.70
02	41.1652832	-72.2125000	Plum Gut	2826	1399	7.08	155.86
03	41.1669596	-72.2125000	Plum Gut (30m below Sea Level)	2826	1399	5.06	155.86
04	41.1665446	-72.2513835	Orient River	2841	1399	5.06	100.95
05	41.1944499	-72.1336182	Great Gull Island	2756	1401	5.57	33.70
06	41.1940389	-72.3180501	Mulford Point	2896	1403	4.05	156.35
07	41.2157674	-72.0971029	Little Gull Island	2736	1401	5.38	172.16
08	41.2183350	-72.1155518	Little Gull Island	2751	1401	5.06	124.56
09	41.2183350	-72.0850016	Little Gull	2746	1401	7.59	185.03
10	41.2333333	-72.0549967	Black Point and Plum River	2731	1205	4.05	144.78
11	41.2333333	-72.0597168	The Race, 0.6 n. mi. NW of Valiant Rock	2731	1205	6.07	241.87
12	41.2449992	-72.0405518	Race Point	2726	1205	6.70	41.90
13	40.5916667	-73.5666667	Jones Inlet, South Coast, Long Island	3616	1471	5.18	22.14
14	40.6294881	-73.3066650	Fire Island Inlet, 0.5 mi S of Oak Beach	3611	1441	4.03	8.43
15	40.8433350	-72.4783366	Shinnecock Inlet	3606	1429	4.31	2.92
16	41.1977824	-72.1986165	Plum Island	2821	1399	4.05	108.28
17	40.5686157	-73.8913818	Roackaway Inlet	3651	1499	4.04	3.00
18	41.0750000	-72.3388346	Montauk Point	2526	1405	4.55	38.97
19	41.0833333	-71.8500000	Montauk Point	2531	1425	4.04	25.73
20	41.0411174	-72.3208333	North Haven Peninsula, N of, Gardiners Bay	2661	1413	4.04	44.70

Number of Long Island Sites Considered: **20**

Note:

1. *The* **Currents** *&* **Tides Stn. ID** *are the reference stations from which the water speed and water depth were taken respectively (taken from Tides and Current™ by Nobletec Corporation)*
2. *The* **Max Water Speed (Knots)** *is the identified maximum water speed for the location refenced by the* **Current Stn***.*

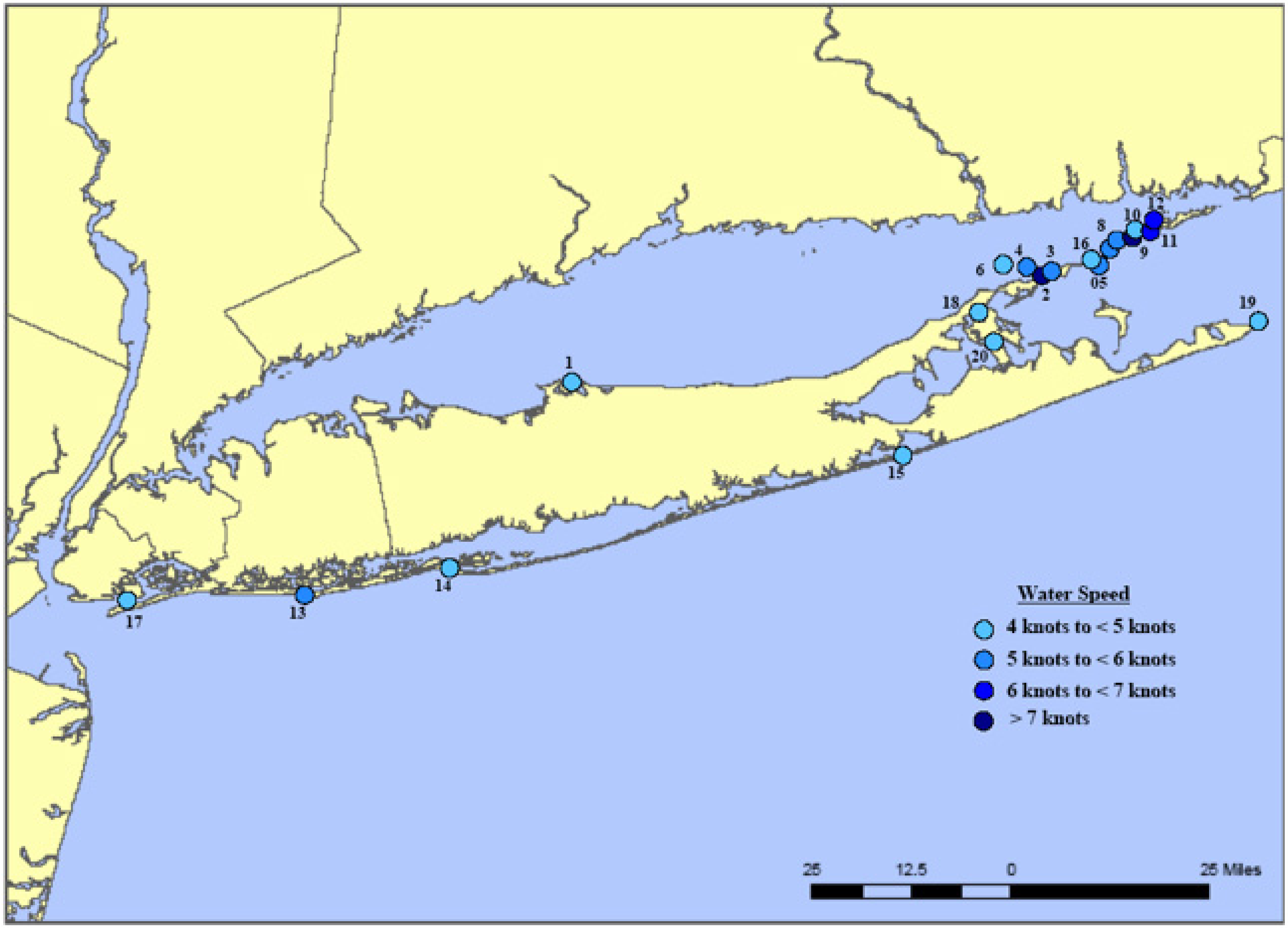


Figure 2.1 Potential Tidal Energy Sites Around Long Island, NY[iv]

Table 2.2 Sites With Depth < 50ft, Long Island

Site #	Latitude	Longitude	Site Name	Currents ID	Tides ID	Max Water Speed (Knots)	Water Depth (ft)
01	40.9666667	-73.1000000	Port Jefferson Harbor Entrance	3106	1377	4.49	10.70
02	41.1944499	-72.1336182	Great Gull Island	2756	1401	5.57	33.70
03	41.2449992	-72.0405518	Race Point	2726	1205	6.70	41.90
04	40.5916667	-73.5666667	Jones Inlet, South Coast, Long Island	3616	1471	5.18	22.14
05	40.6294881	-73.3066650	Fire Island Inlet, 0.5 mi S of Oak Beach	3611	1441	4.03	8.43
06	40.8433350	-72.4783366	Shinnecock Inlet	3606	1429	4.31	2.92
07	40.5686157	-73.8913818	Roackaway Inlet	3651	1499	4.04	3.00
08	41.0750000	-72.3388346	Montauk Point	2526	1405	4.55	38.97
09	41.0833333	-71.8500000	Montauk Point	2531	1425	4.04	25.73
10	41.0411174	-72.3208333	North Haven Peninsula, N of, Gardiners Bay	2661	1413	4.04	44.70

Number of Long Island Sites Considered: **10**

<u>**Note:**</u>

1. *The* **Currents** *&* **Tides Stn. ID** *are the reference stations from which the water speed and water depth were taken respectively (taken from Tides and Current™ by Nobletec Corporation)*
2. *The* **Max Water Speed (Knots)** *is the identified maximum water speed for the location refenced by the* **Current Stn***.*

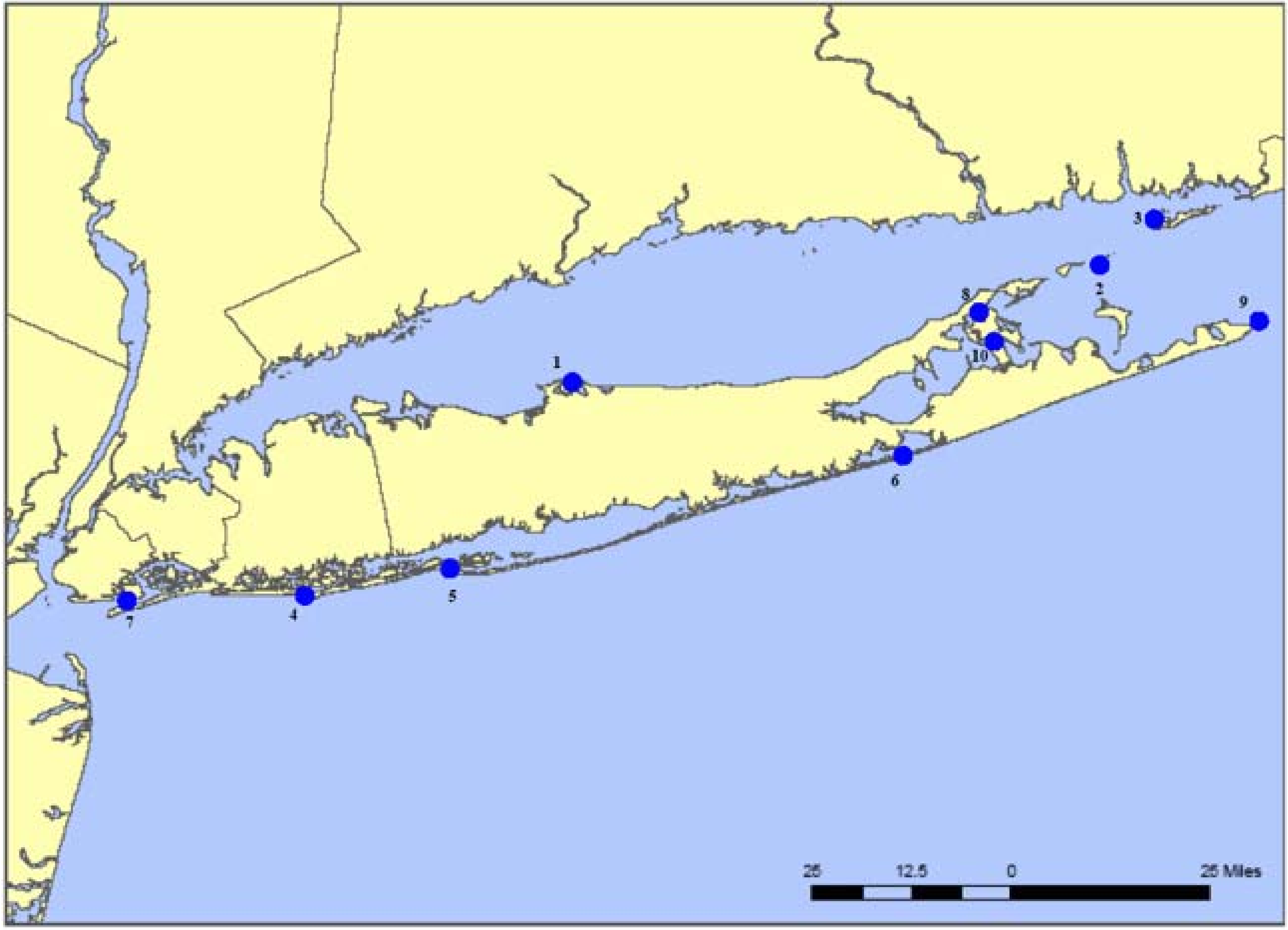


Figure 2.2 Potential Tidal Energy Sites with Depth < 50 ft, Long Island[4]

Table 2.3 Sites with Depth > 50ft, Long Island

Site #	Latitude	Longitude	Site Name	Currents ID	Tides ID.	Max Water Speed (Knots)	Water Depth (ft)
01	41.1652832	-72.2125000	Plum Gut	2826	1399	7.08	155.86
02	41.1669596	-72.2125000	Plum Gut (30m below Sea Level)	2826	1399	5.06	155.86
03	41.1665446	-72.2513835	Orient River	2841	1399	5.06	100.95
04	41.1940389	-72.3180501	Mulford Point,	2896	1403	4.05	156.35
05	41.2157674	-72.0971029	Little Gull Island	2736	1401	5.38	172.16
06	41.2183350	-72.1155518	Little Gull Island,	2751	1401	5.06	124.56
07	41.2183350	-72.0850016	Little Gull	2746	1401	7.59	185.03
08	41.2333333	-72.0549967	Black Point and Plum River	2731	1205	4.05	144.78
09	41.2333333	-72.0597168	The Race, 0.6 n. mi. NW of Valiant Rock	2731	1205	6.07	241.87
10	41.1977824	-72.1986165	Plum Island	2821	1399	4.05	108.28

Number of Long Island Sites Considered: 10

Note:

1. *The* **Currents** *&* **Tides Stn. ID** *are the reference stations from which the water speed and water depth were taken respectively (taken from Tides and Current™ by Nobletec Corporation)*
2. *The* **Max Water Speed (Knots)** *is the identified maximum water speed for the location refenced by the* **Current Stn***.*

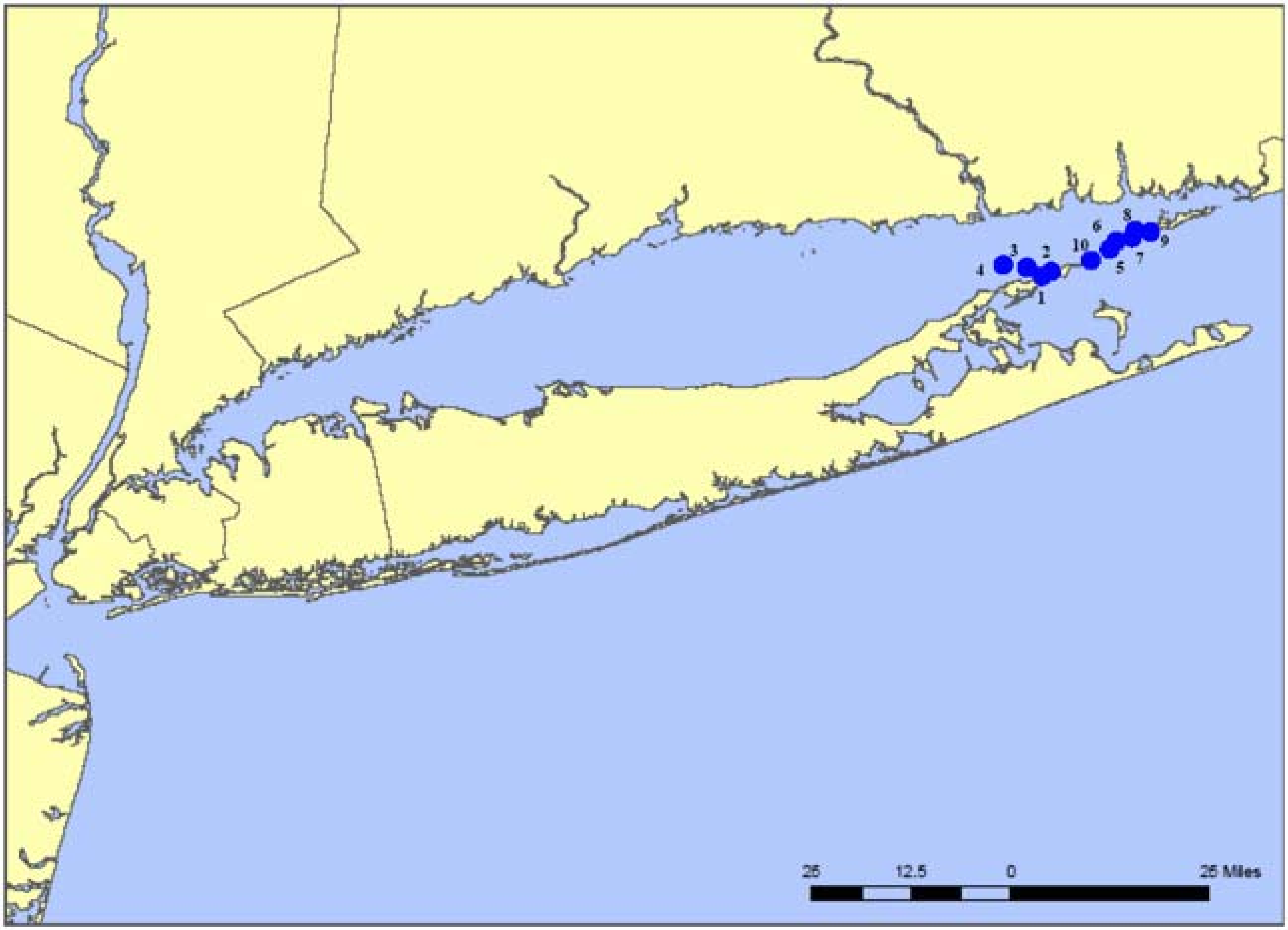


Figure 2.3 Potential Energy Sites with Depth > 50 ft, Long Island[4]

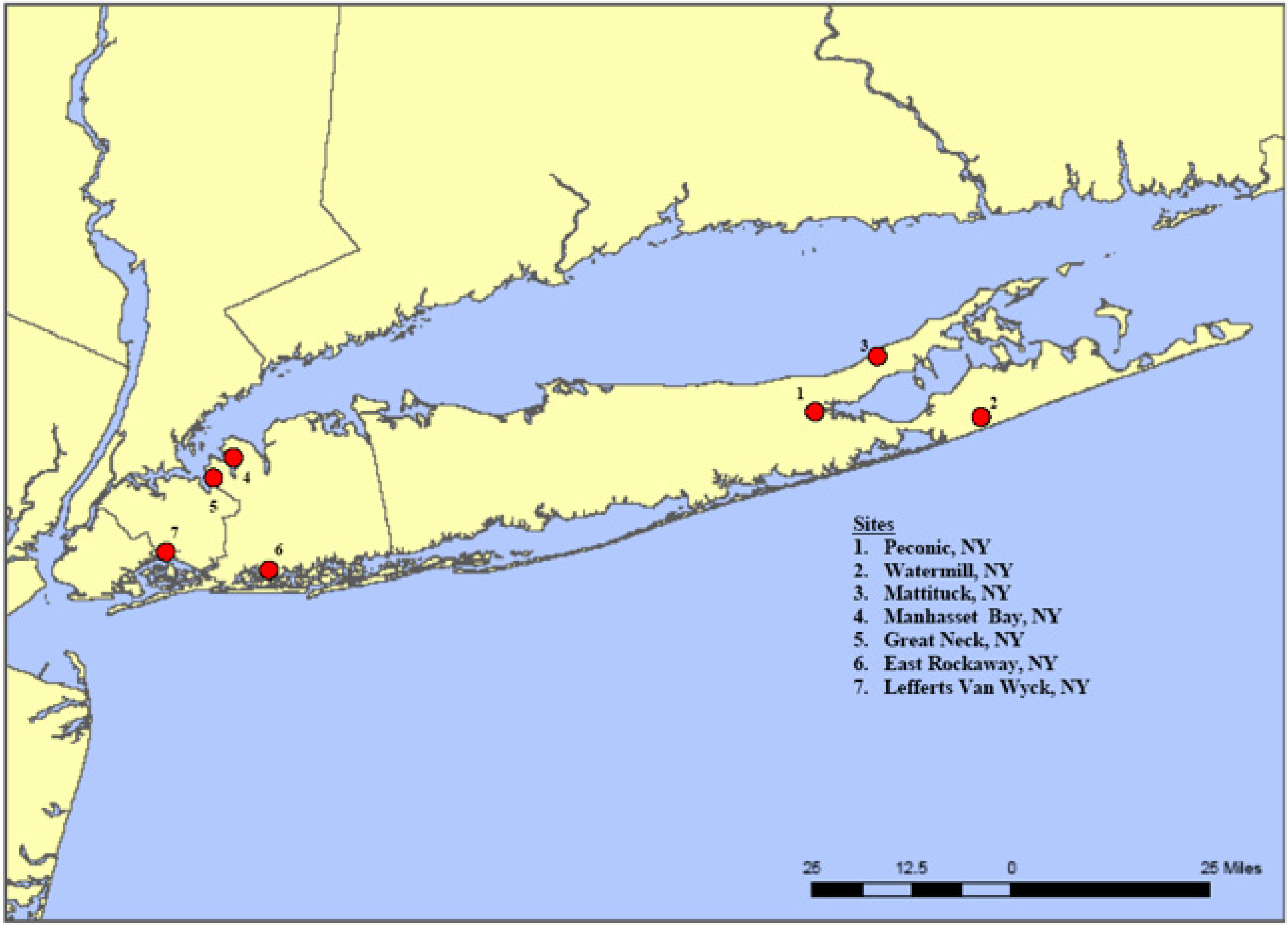


Figure 2.4 Historical Tidal Sites Around Long Island, NY (Operational 1644 to 1990) [4]

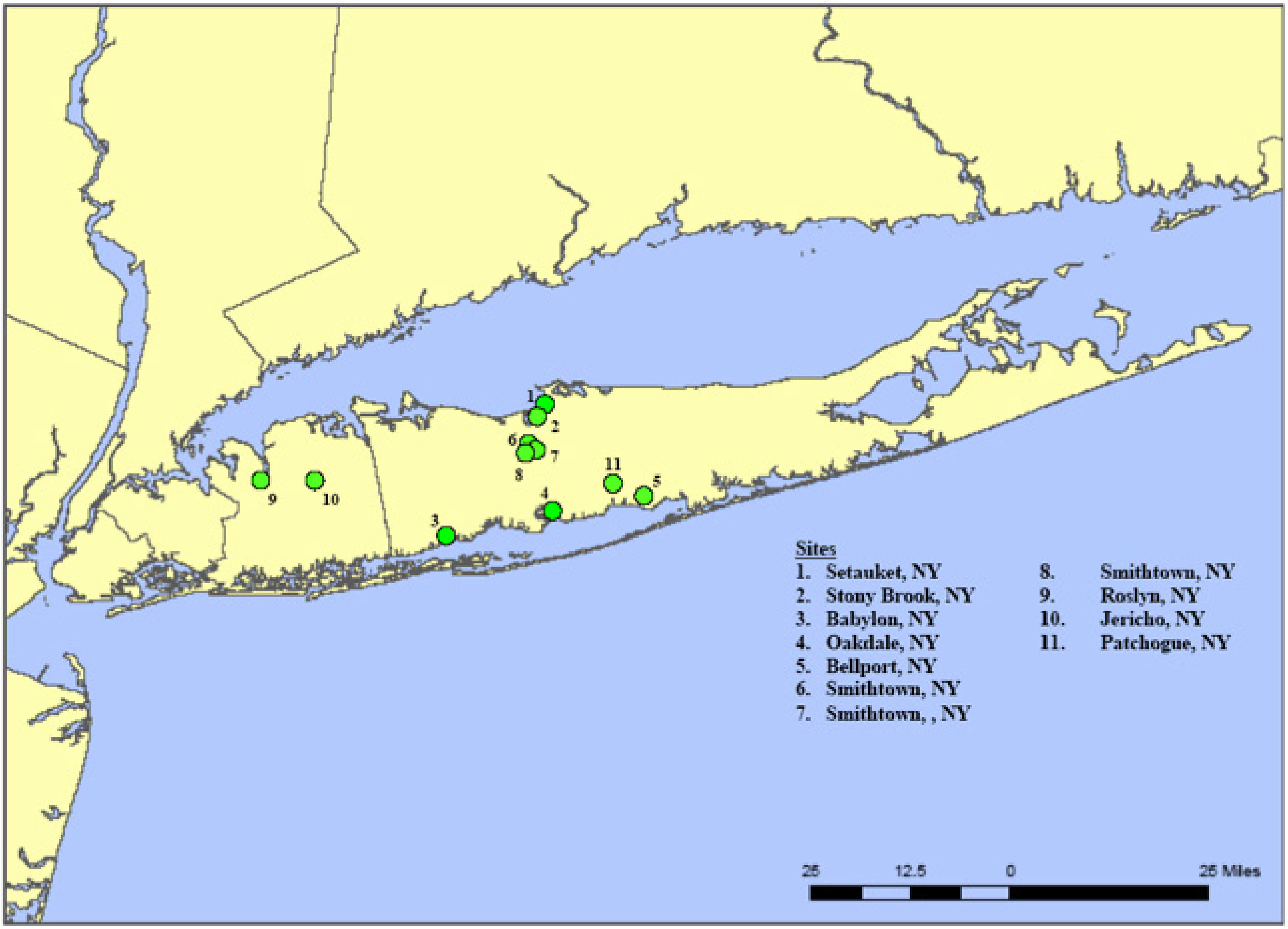


Figure 2.5 Hydro/Mill Resources Around Long Island, NY (Operational 1698 to 1900) [4]

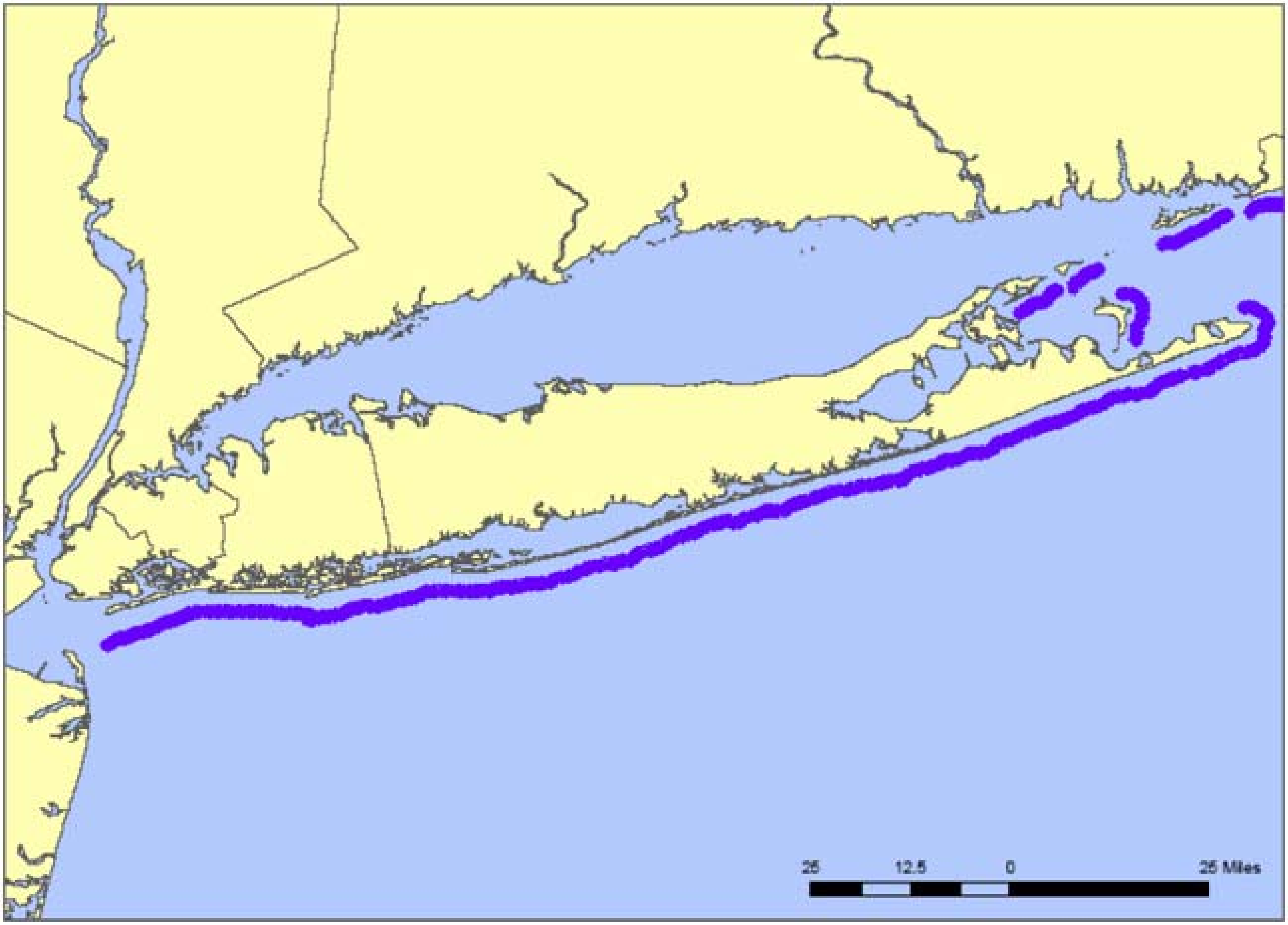


Figure 2.6 Preliminary Wave Energy Resource on Long Island, NY[4]

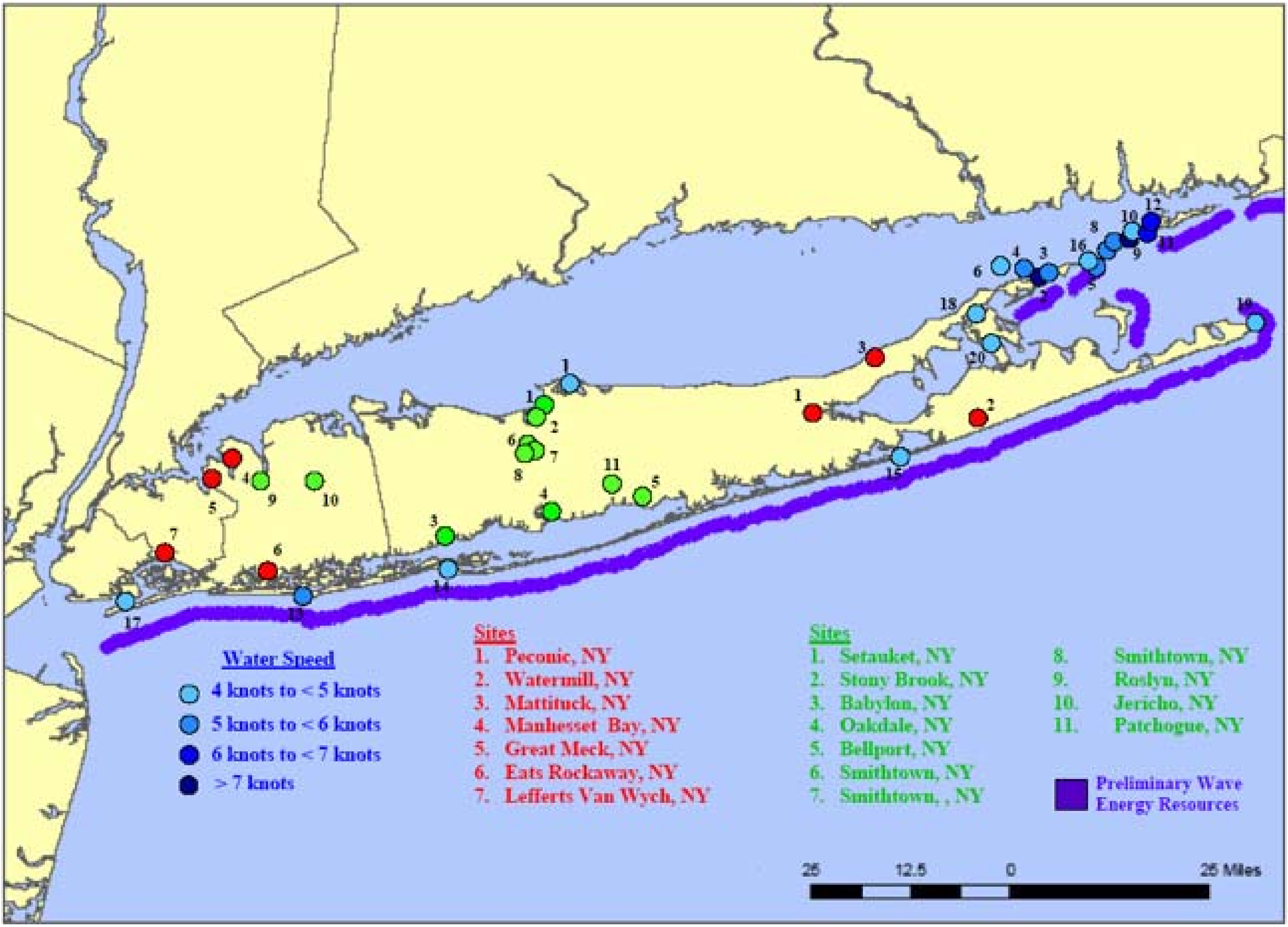


Figure 2.7 Hydro, Tidal and Wave Resources on Long Island, NY[4]

2.2 Wave Power Resources

The two largest inventories of long-term measured wave data in the United States are maintained by the National Data Buoy Center (NDBC) of the National Oceanic and Atmospheric Administration (NOAA) and the Coastal Data Information Program (CDIP). Field data collection by ocean deployed buoys is accomplished by accelerometers that measure wave conditions. Wave spectra are computed from 17-minute time series measurements of sea surface elevation changes and these records are archived at six-hour intervals.

From these databases, two critical parameters are used to determine the amount of energy that may be extracted from the wave for possible conversion to electricity generation. These include sea-state measurements using the buoys to determine the wave height ($\mathbf{H}_s$ in meters), and the peak wave period ($\mathbf{T}_p$ in seconds). Based on these two parameters, the incident wave power or the power available in a linear meter of wave front is determined. This can be calculated as follows, where the power **J** is calculated in kilowatts per linear meter of wave front or kW/m.

$$\mathbf{J} = 0.42 \times (\mathbf{H}_s)^2 \times \mathbf{T}_p$$

The 0.42 multiplier in the above equation is exact for most prevailing wave and swell conditions. This value could range from 0.3 to 0.5, depending on relative amounts of energy in sea and swell components and the exact shape of the wave spectrum, but for this level of analysis is considered sufficiently accurate.

Of critical importance is the overall mechanical-electrical conversion efficiency of the WEC technology. For example, Grilli et al (2005) [5,6] recently performed a very comprehensive analysis of the potential power production of the Energetech vertical oscillating water column plant for a site off Pt Judith, RI (Figure 3.2b, picture). Grilli first estimated the wave energy flux using the most recent update to the US Army Corp WIS data set. The value in the vicinity of site 83 (old WIS site, see Figure 2.8) was 5.78 kW/m. This compares to Hagerman's estimate based on the prior WIS data set of 9 kW/m

(Grilli's most recent analysis is about 2/3 of Hagerman's estimate) and Giannotti's estimate of 10.56 kW/m[7]. After corrections for operating constraints of the system for wave amplitude, period, and direction (and after optimization for directional orientation) the available wave energy flux decreases to 3.4 kW/m. After consideration for the measured efficiency (hydrodynamic, aerodynamic, and electrical) of the power plant and generator the value was further reduced to 1.3 W/km. This represents about 20 % of the total power available. Due to the parabolic arms that focus the waves in the Energetech system, it was projected to have a capture length of 27 m and hence the output would be 35 kW. The analysis also showed that the system would only operate 45 % of the time. During the remaining time either the waves were too small in amplitude (less than 0.5 m), too large in amplitude (greater than 3 m) or too short in period (less than 5 sec)[5].[6]

2.3 Wave Energy Summary

Wave power opportunities for Long Island off-shore areas as presented in Figures 2.6 and 2.7 are evaluated as borderline at best for economically viable Wave Power development on a large scale. The west coast of continents throughout the world present the major wave energy resource because prevailing winds that generate this resource move from west to east in the northern hemisphere. Long Island is highly restricted in its fetch from this prevailing wave direction due to its location on the east coast, therefore its potential for wave power development is much reduced. Most experts in the industry have concluded that a borderline value of 25 to 30 kW per linear meter of wave front is necessary for economical development of the resource, based on presentations of economic analyses and discussions with three major technology developers including Alla Weinstein, (Aqua Bouy), Des McGinnes (Pelamis) and Annette von Jaunne (Oregon State University). Average Long Island values are below this borderline power generation value. Local wave data taken over a seven year period (1993-2000) indicates that wave resources off the south shore of Long Island range from 7 to 11 kW/m. [6]Cape Cod off-shore wave energy potential, which should be similar to Long Island, indicates an average annual wave Power Density of 13.8 kW/m[7]. Information presented in the following two pages indicated by **Figures 2.8 and 2.9** reveal the location of data taken from WIS Station #101 off the eastern end of Long Island. The Rose plot provides an overview of wave direction coming primarily from the south. Details of this data further indicate that the Power Density is low, based high percentage of waves that are 1 m or less.

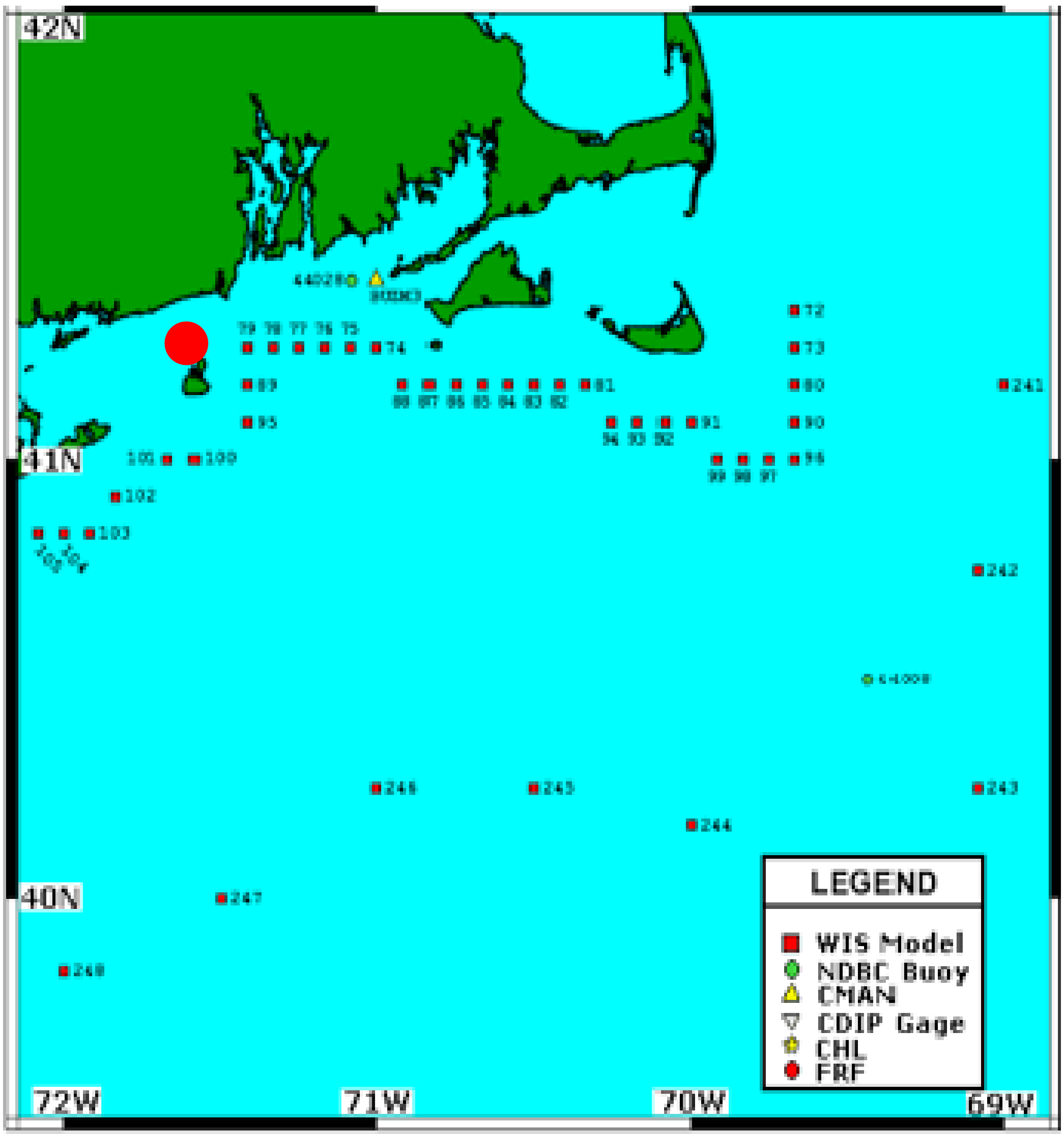


Figure 2.8: Location of WIS Stations Off Eastern End of Long Island (USACE)

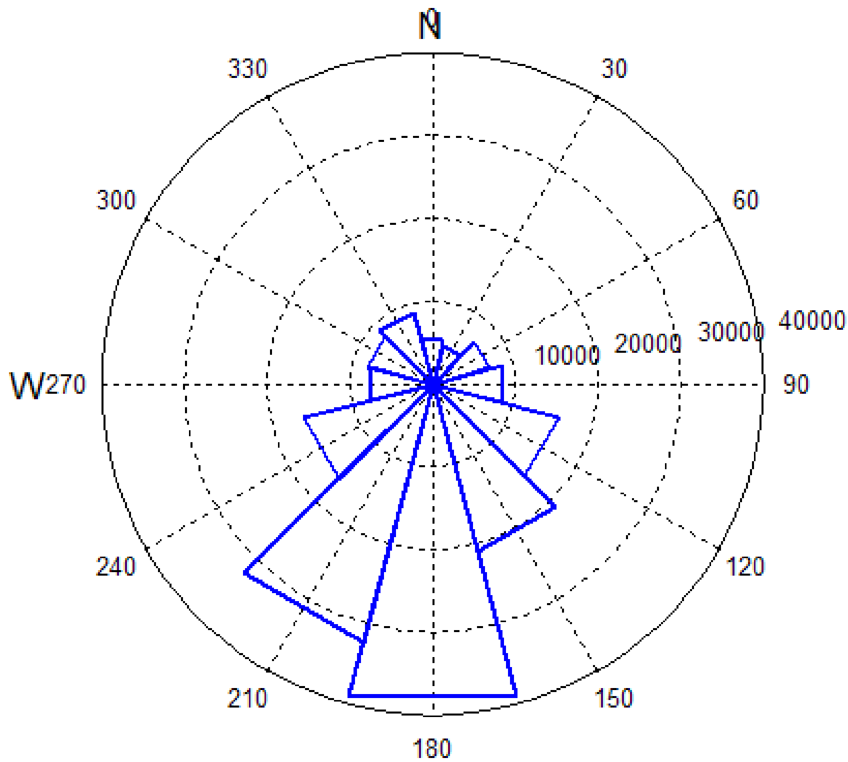


Figure 2.9: Rose Plot Showing Wave Direction Frequency at WIS station #101 (1980-1999)

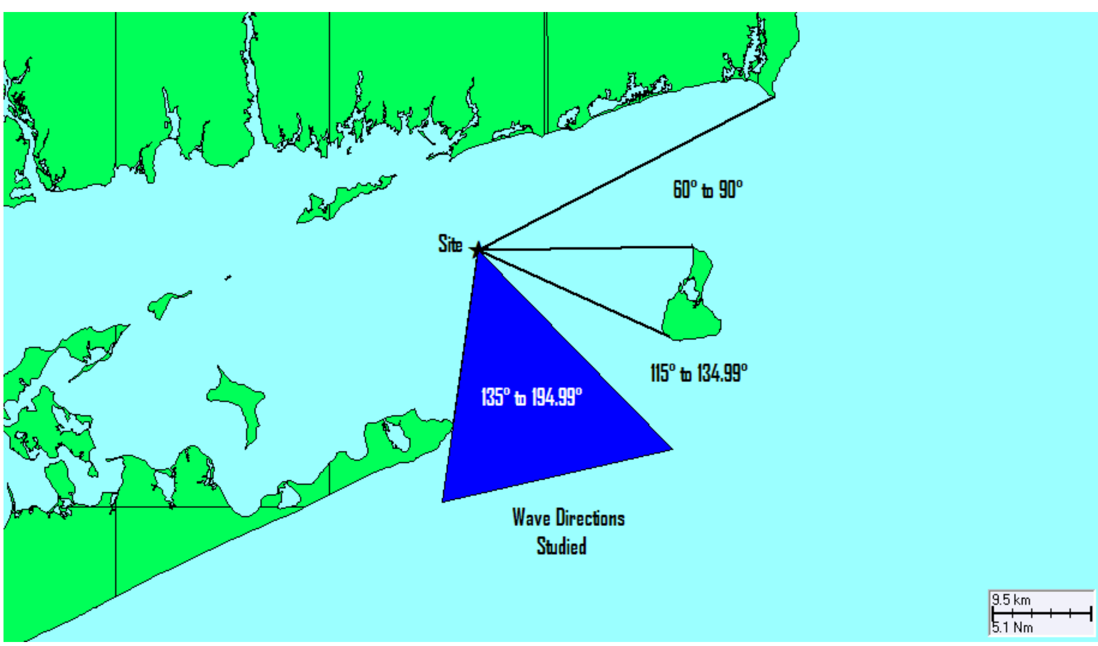


Figure 2.10: Map Showing Wave Directions Considered in a Recent URI Study

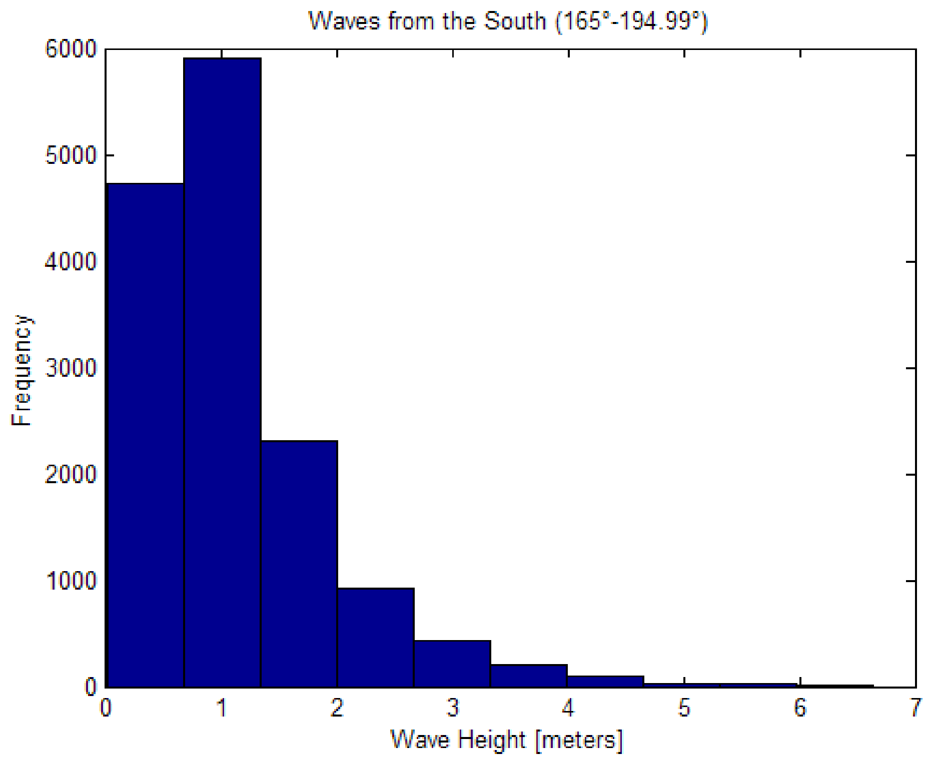


Figure 2.11 - Histogram of Monthly Maximum Wave Heights @ WIS # 101 from South

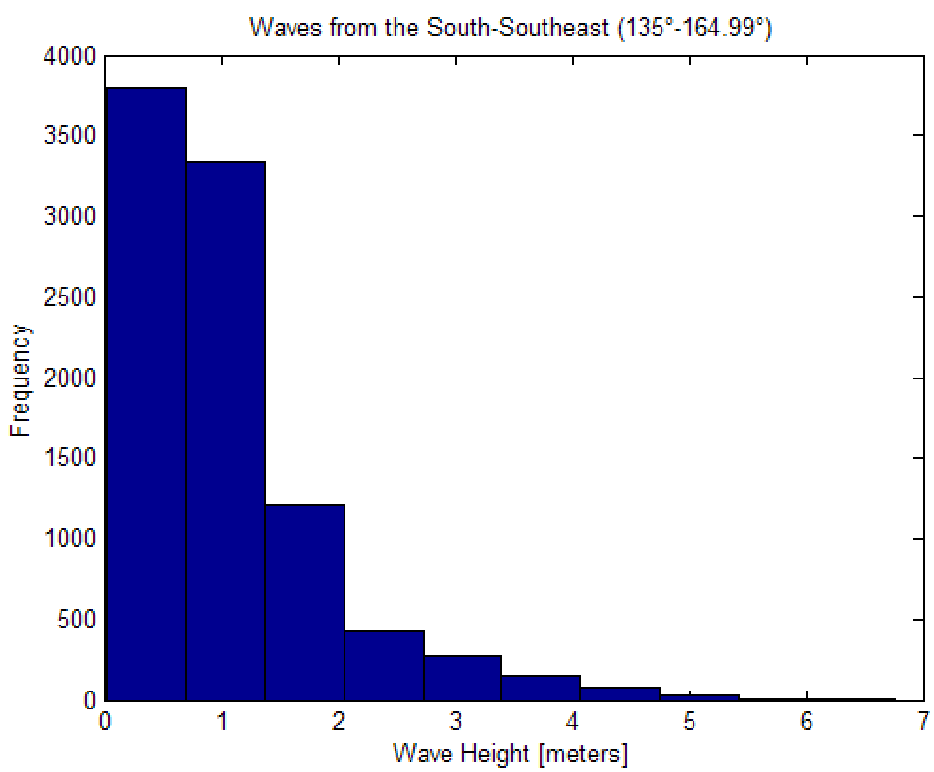


Figure 2.12 - Histogram of Monthly Max. Wave Heights @ WIS #101 from the S-SW

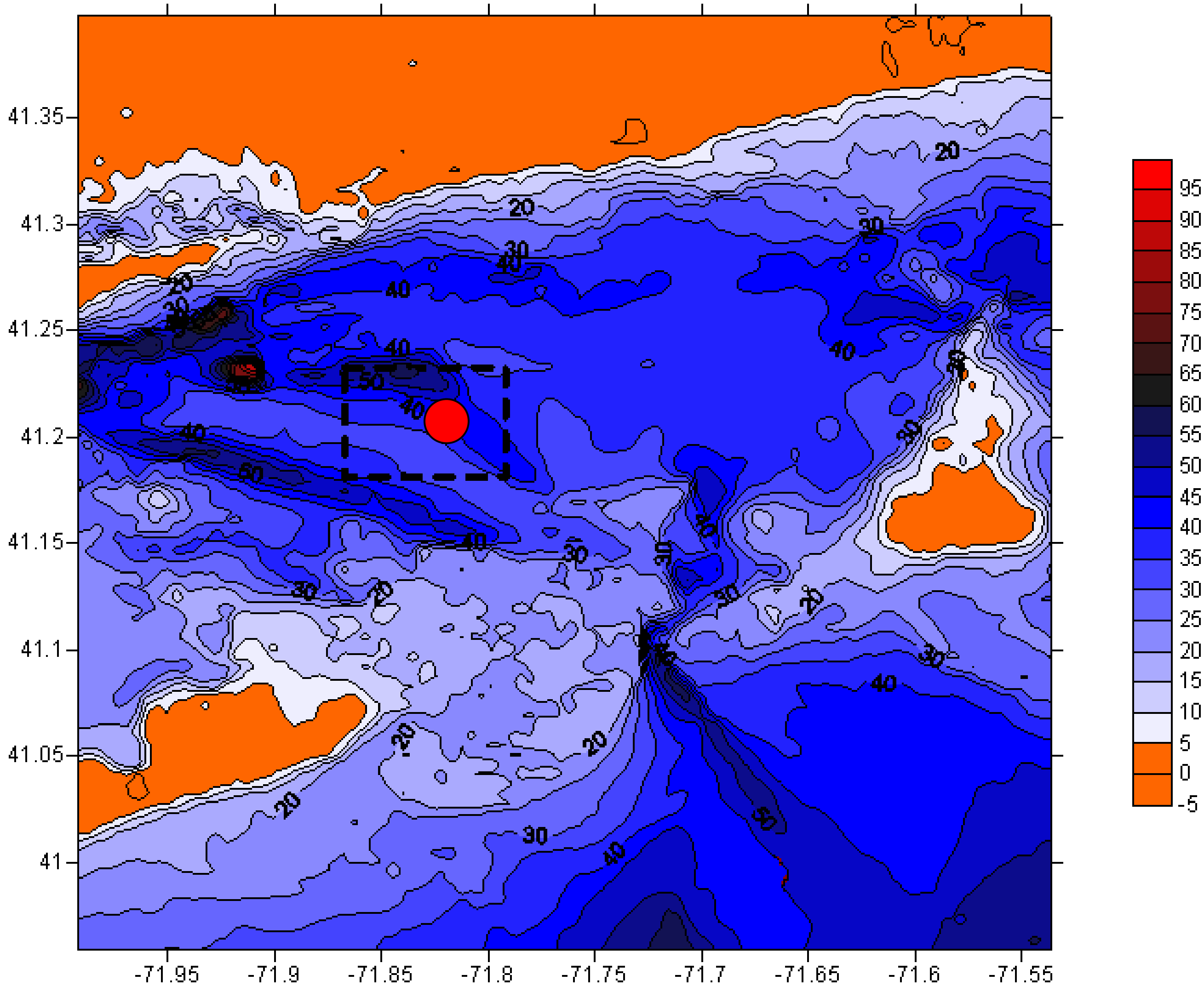


Figure 2.13 - Bathymetry Map of Block Island Sound.
Red Dot is reference location with data in detailed in Figures 2.8, 2.9, 2.10, 2.11, and 2.12. Legend on the right indicates depth in feet.

3. Status of Tidal and Wave Technologies

This section presents an overview of applicable technologies including tidal energy systems (TISEC) and wave energy conversion (WEC) systems. These two technologies are different in many respects. They are usually deployed in completely different conditions (TISEC requires flowing currents and WEC requires periodic wave motion). While the operational conditions are usually different, complementary ocean environments suitable for each system may be in fairly close proximity depending on the site.

3.1 Overview of Tidal In-Stream Energy Conversion (TISEC) Technology

Tidal in-stream energy conversion (TISEC) devices contain a rotating element that turns when impacted by flowing waterways such as tidal currents and convert this mechanical rotational movement into electricity using a gearbox and electrical generator. These systems are generally one of two primary types:

Horizontal axis – This technology type most closely resembles a modern wind turbine in design, with blades rotating in a plane perpendicular to the axis, which is oriented into the direction of the flow or tidal current. Examples include Sea Gen's Marine Current Turbines and the Verdant Power demonstration in the East River near Roosevelt Island.

Vertical Axis – Vertical axis turbines have their blades oriented parallel with the axis of rotation rather than perpendicular to it. An early example of this was the Darrieus turbine, which looks like an eggbeater. A more recent variation is the Gorlov Helical Turbine (although this device may in fact be deployed such that the axis is oriented either horizontally or vertically). This system has been tested off the south shore of Shelter Island, NY in a short demonstration deployment that was co-sponsored by the New York State Energy Research and Development Authority (NYSERDA) and LIPA in 2004. Other types of in stream devices have been proposed – for example, oscillatory devices and hydro venturi turbines; however, none of them are developed to the point of significantly affecting the emergence of this new technology.

3.2 TISEC Power Production

TISEC devices are akin to underwater windmills. They operate purely by the conversion of the kinetic energy of the natural water current. For power production, the output of such turbines can be estimated by the power equation below:

$$P\ (kW) = 0.5*\eta*\rho*A*v^3$$

η = mechanical turbine efficiency (%/100)

ρ = density of seawater (kg/m^3)

A = area of turbine cross-section (m^2)

v = water current velocity (m/sec.)

For a turbine efficiency of 35%, operating in a 3 m/sec. current (6 knots), the energy conversion would be 4 kW for the turbine cross section (the cross section is approximately 2.5 m^2)or approximately 1.6 kW per m^2 . For the same turbine operating in a 4 m/sec. current (8 knots), the energy conversion would be 28 kW per m^2 of turbine cross section or 11.2 kW per m^2.

Tidal energy extraction is complex and many different designs have been proposed. The Electric Power Research Institute (EPRI) has conducted many interviews during the past two years and has assembled baseline data on generalized sites and technologies.

Typical components of these systems include: (1) rotor blades, which convert energy from water currents into rotational motion, (2) the drive train, usually consisting of a gear box and generator that converts the rotational shaft motion to electricity, and (3) a structure which supports the rotor blades and gear train.

Other key elements that distinguish various types of devices include:

- Support Structure Types – can be (1) bottom mounted, (2) supported by pylons and resemble underwater wind mills, and (3) barge / dock mounted systems.
- Rotors – can be (1) shrouded (ducted) or (2) open to the water flow.
- Blades - can be (1) fixed or (2) variable pitch.
- Yaw – or directional adjustment to the flow can be (1) fixed or (2) controllable angle.
- Vertical Axis Turbines – can be motivated by (1) Drag and / or (2) Lift forces.

Tidal power research programs in industry, government and at universities in the UK, Norway, Ireland, Italy, Sweden, Denmark, Canada and the US over the past five or six years, have established an important foundation for the emerging tidal power industry.

There is strong leadership by several small companies that are backed by private industry, venture capital, and European governments to generate electricity from tidal flows. The recent EPRI assessment of the industry identified eight (8) different devices in an effort to determine the maturity of the technology and readiness for the commercial marketplace. These technologies are compared in a series of charts and figures below. [1]

3.3 TISEC Technology

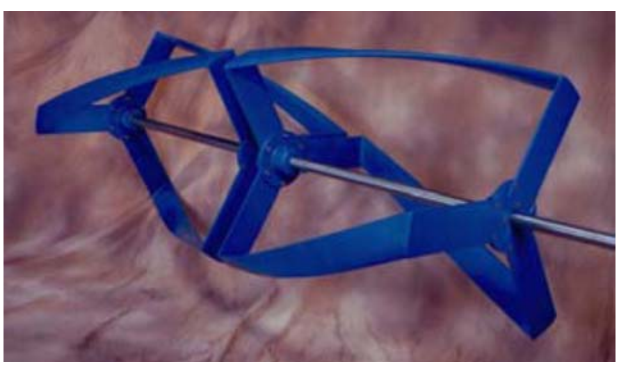
Table 3.1 - Summary of TISEC Devices and Characteristics (EPRI) presents an overview of eight (8) TISEC systems and their comparative output, relative size and system type (V = vertical axis, H= horizontal axis). These systems are presented in **Figures 3.1 - Tidal In-Stream Energy Conversion Technologies.**

Table 3.1 - Summary of TISEC Devices and Characteristics (EPRI)[8]

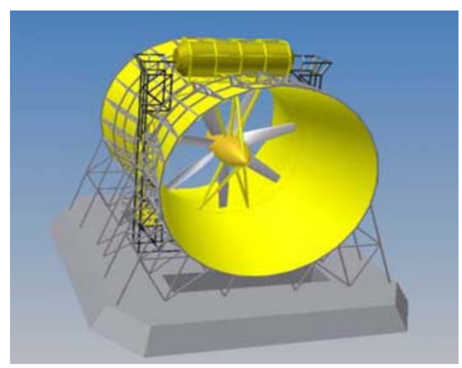
	GCK	Lunar	MCT	Open Hydro	Sea Power	SMD Hydro	UEK	Verdant
Axis Type	V axis Lift	H Axis Duct	H axis Dual	H axis Rim Gen	V axis Drag	H axis Dual	H Axis Dual	H axis
Rotor Diameter	1 m dia	21 m dia	18 m dia	15 m dia	1 m dia	8 m dia	3 m dia	5 m dia
Rated Power	7 kW	2 MW	1.5 MW	1.5 MW	44 kW	1 MW	400 kW	34 kW

The systems listed in Table 3.1. are presented in the following eight photographs (Figure 3.1). Four are horizontal axis turbines (2, 3, 6, 8) and four are cross flow systems (1, 4, 5, 7).

Figures 3.1 - Tidal In-Stream Energy Conversion Technologies

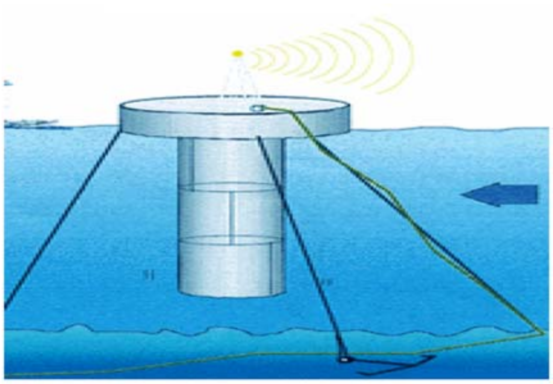


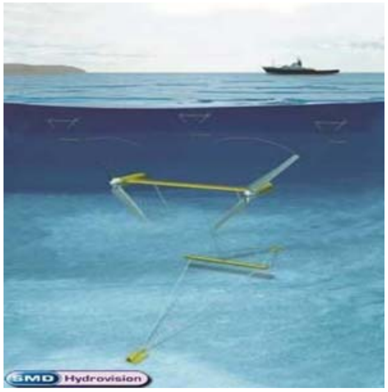
1 – Gorlov Helical Turbine



2 - Lunar

3 – MCT 4 – Open Hydro





5 – Sea Power 6 – SMD Hydro

7 – UEK 8 - Verdant

Table 3.2 presents information about some of the major tidal "fields" where large-scale power projects may be developed. These fields were selected from the limited range of sites evaluated an initial EPRI study[8] and did not look at small, near shore tidal power opportunities, but was a "first-cut" analysis of large-scale sites. The EPRI study included analysis of the states of Alaska, Washington, California, Massachusetts, Maine and two Canadian Maritime provinces New Brunswick and Nova Scotia. The assumptions made in the site analysis include the (1) site, (2) rated power, (3) number of units, (4) average power output and (5) number of homes powered given 1.3 kW per home (IEA).

Table 3.2 - Site Analysis for Major Tidal Power Fields in US and Canada (EPRI)[8]

	AK	WA	CA	MA	ME	NB	NS
Site	Knik Arm	Tac Narr's	Golden Gate	Musk-eget	West Pass	Head Harbor	Minas Pass
Unit Rated Power (MW)	0.76	0.7	1.1	0.46	0.83	0.31	1.11
Unit Rated Speed (m/s)	1.9	1.9	2.1	1.6	2.0	1.4	2.2
Unit Avg Yrly Power (MW)	0.22	0.21	0.37	0.18	0.38	0.13	0.52
# of Com'l Units	66	64	40	9	12	66	250
Avg Power (MW)	14.6	13.7	16.5	1.6	4.6	7.3	130
1000 Homes Powered	11.2	10.5	12.8	1.3	3.5	6.5	100

(1) Extractable is 15% of available
(2) Rated power at rated speed is optimized for lowest COE
(3) 1.3 kW per average U.S. home per IEA

Table 3.3 presents an economic analysis of estimated costs for the development of the known sites evaluated in Table 3.2, given best known data for system deployment and permitting costs. Table 3.4 evaluates the projected costs, performance and efficiency of the Tidal In-Stream technologies in general and compares them to other renewable and non-renewable energy sources including coal and various types of natural gas micro-turbines. Four points of comparison are presented. These include:

- **Capacity Factor (%)** – or the average percentage of time the system is generating power during the course of a year.
- **Capital Cost ($/MW)** – which is a factor of the power density, in the case of tidal power systems, that is related to the speed of the tidal water flow.
- **Cost of Electricity (COE – cents/kWh)** – estimated or known cost of electricity expressed in cents per kW-hr.
- **CO2 (lbs/MWh) –** Carbon dioxide per MegaWatt hour of power generation presents a critical value in terms of Global Warming and Climate change criteria. Many nations and some states in the US participate in a market for Renewable Energy Credits (RECs) or bankable credits and trading for proven clean power generation produced without Green House Gases (GHGs) and particularly carbon dioxide.

Table 3.3 - Conceptual Tidal Power Plant Economic Assessment (EPRI)[8]

	AK	WA	CA	MA	ME	NB	NS
Site	Knik Arm	Tac Narr's	Golden Gate	Musk-eget	West Pass	Head Harbor	Minas Pass
Number of Turbines	66	68	40	9	12	66	250
Total Plant Cost ($M)	110	103	90	17	24	68	486
Yrly Level O&M Costs	4.1	3.8	3.6	0.6	1.0	2.3	18
Annual Energy (GWh)	128	121	129	1.5	40	64	1,140
Utility Gen COE	9.2 – 10.8	9.0 – 10.6	6.6 – 7.6	8.6 – 9.9	5.6 – 6.5	10.0 – 11.7	3.9 – 4.6
Muni Gen COE	7.1 – 8.4	7.2 – 8.4	4.9 – 5.6	6.0 – 6.7	4.2 – 4.8	9.2 – 11.2	3.9 – 4.6
Non Utility Gen IRR	None	None	21%	None	34%	None	31%

Cost of Electricity (COE) in U.S. cents/kWh

Table 3.4 - Comparative Costs of TISEC System Deployments (EPRI)[8]

	Capacity Factor (%)	Capital Cost (1) ($/MW)	COE (2) (cents/kWh)	CO_2 (lbs per MWh)
Tidal In-stream Power Den > 3.0 Power Den 1.5 – 3.0 Power < 1.5 kW/m2	29 – 46	1.7 – 2.0 2.1 – 2.4 3.3 – 4.0	4 – 7 4 – 11 6 - 12	None None None
Wind (class 3 – 6)	30 – 42	1.2 – 1.6	4.7 – 6.5	None
Solar Thermal Trough	33	3.3	18	None
Coal PC USC (2)	80	1.3	4.2	1,760
NGCC @ $5/MM BTU (3)	80	0.5	4.8	860
NGCC @ $7/MM BTU (3)	80	0.5	6.4	860
IGCC with CO_2 Capture (4)	80	1.9	6.1	344

(1) All costs in 2005 US$
(2) 600 MW Plant, Pittsburgh #8 Coal
(3) (3) GE 7 F machine of equivalent
(4) 80% removal

3.4 Wave Energy Conversion (WEC) Technology

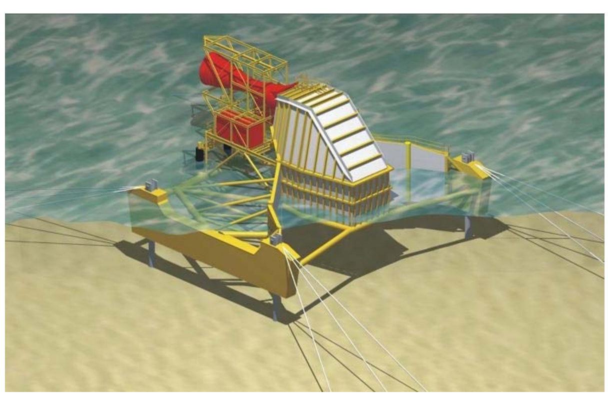
Wave energy conversion devices create a system of reacting forces, in which two or more bodies move relative to each other, while at least one body interacts with the waves. The body moved by the waves is called the *displacer*, while the body that reacts to the displacer is called the *reactor*. There are many ways that such a system may be configured. The best-known wave energy conversion device concepts are described below:

Terminator – A terminator is any structure that extends perpendicular to the predominant wave direction. One example of a terminator is a breakwater – essentially, a wall. However, a breakwater merely reflects or diverts the energy of oncoming waves without capturing any of that energy. Some form of displacement-reaction must be employed to capture the power that would otherwise be reflected or absorbed by the terminator, an example of which is the Limpet (Figure 3.2a)

Figure 3.2 a – Limpet, Scotland
Terminator

Oscillating Water Column – An oscillating water column (OWC) consists of a partially submerged structure (the collector), which is open to the sea below the water surface so that it contains a column of water with air trapped above it. As waves enter and exit the collector, the water column moves up and down and acts like a piston, pushing the air back and forth. The air is channeled towards a turbine and forces it to turn, generating electricity, such as the Energetech system pictured below (Figure 3.2 b).

Figure 3.2 b - Energetech – Australia
Oscillating Water Column



Point-absorber – Whereas a terminator is designed to absorb energy coming predominantly from one direction, a point absorber is a floating structure that absorbs energy from all directions by virtue of its movements at or near the surface of the water. The amount of power available for capture may be maximized by designing the device to resonate by moving with larger amplitudes than the waves themselves. An example of such a system is the Aqua Energy system (Figure 3.2c).

Figure 3.2 c - Aqua Energy – USA
Point Absorber

Attenuator – Like a terminator, an attenuator is a long floating structure. However, unlike a terminator, an attenuator is oriented parallel to the predominant direction of travel of the waves. It rides the waves like a ship, extracting energy by virtue of restraints at the device's bow and along its length, such as the Pelamis systems (Figure 3.2d).

Figure 3.2 d - OPD Pelamis – Scotland
Linear Absorber Attenuator

Overtopping Devices – An overtopping device is essentially a floating reservoir, a partially-submerged structure consisting of walls over which waves topple, filling the reservoir and creating a head of water which turns hydro turbines at the bottom of the reservoir as the water is released back into the ocean. An example of such a system is the Wave Dragon (Figure 3.2e).

Figure 3.2 e - Wave Dragon – Denmark
Overtopping Devices

Apart from their conceptual design and configuration, wave energy conversion devices may be characterized in terms of their *placement* or location. Wave power may be captured either at the shoreline, near to shore, or offshore. The distinction between "near shore" and "offshore" is not rigidly defined. It may be a function of distance from the shoreline, depth of water, or both. Devices typically are optimized for operation within a particular depth range. Both water depth and the energy content of the waves tend to increase with distance from shore. Distance from shore also affects accessibility (for deployment, retrieval, operation, and maintenance) and visual impact; at any given site the distance from shore will also determine what aspects of the marine resource may be affected. Another characteristic distinguishing different types of wave energy conversion devices is the method of *fixing* the device to the site. Bottom-mounted devices are fixed to the seabed by a static member. Floating devices are anchor moored to the sea bed.

3.5 Summary of the Industry

Wave technologies share some similar needs for system deployment with tidal energy industry. These include integration with marine services, similar site and permit requirements and assessment of environmental impacts on ocean and marine life.

They do, however, generally occupy very different niches with respect to the type of water conditions that optimize power production. The two technologies generally do not compete for the same ocean space. Wave systems seek active wave environments with a high and steady level of ocean wave energy during the course of each year with a minimal impact of severe storms.

Tidal power systems seek generally different conditions; that is, strong tidal flows without waves. In addition to the over 1,000 patents currently filed for Wave Energy Conversion devices, a recent review of over 30 business plans for the NREL Venture Forum (2006) indicate that there are many more wave energy technologies on the way. What are referenced in this section are the five basic technology types: (1) Terminator, (2) Oscillating Water Column, (3) Linear Absorber Attenuator, (4) Overtopping Devices, and (5) Point Absorber.

4. Key Issues for Tidal and Wave Energy on Long Island

4.1 Regulatory Overview

The modern era of tidal and wave energy development is in its infancy. While technology development is advancing in some 20 nations around the world, the application of TISEC and WEC systems have few installed commercial scale systems by which to evaluate the regulatory process. Most projects are pilot and demonstration scale systems that form the basis for historical review of the regulatory process.

Approximately fifteen (15) federal, state, and local resource agencies have been identified to date that have some oversight and may evaluate potential tidal and wave energy projects with respect to potential environmental impacts or regulatory jurisdiction for permitting. An initial review of the responsibilities of each of these agencies has been conducted. Preliminary evaluations to date have requested a generalized view and understanding with respect to key concerns such as threatened and endangered species, navigational issues, impacts on sediments and benthos, public safety and among other issues.

Cooperative agencies for environmental impact assessments include:

US Army Corps of Engineers – US ACE
US Fish and Wildlife Service – US FWS
US Coast Guard – USCG
National Oceanic and Atmospheric Administration – NOAA
Federal Energy Regulatory Commission – FERC
National Marine Fisheries - NMF
New York State Department of Environmental Conservation – NYS DEC
New York State Department of State – NYS DOS per SEQR
New York State Coastal Management Program – NYS CMP
Local Community Planning Boards

4.2 FERC Authority on Tidal and Wave Projects

Several key issues are emerging in the field of system permitting in the United States. Most critical at this time are developments within the Federal Energy Regulatory Commission.

Pursuant to Part I of the Federal Power Act of 1978 (FPA), FERC has authority to issue preliminary permits and licenses for the construction and operation of hydroelectric projects on navigable waters, public lands and reservations or which impact interstate commerce through interconnection to the electric grid or interstate commerce.

Currently FERC provides a 3-year window to complete related studies for companies developing given tidal or wave energy sites. These preliminary permits may be extended an additional 3 years making a total of six (6) years for system development and related environmental studies. Many view this process as so long as to deter private investment.

The time involved for permitting is further lengthened because many agencies do not yet have a knowledge base or precedent for reviewing this relatively new and emerging technology. A Preliminary FERC Permit gives companies incentive to take the risk of investing money to gather necessary data and prepare a license application. The Preliminary FERC Permit guarantees the company an exclusive right to file a license application during the term of the permit and a first-filed priority over later filing competitors.

As of December, 2006 FERC is re-evaluating the criteria by which preliminary applications for tidal and wave energy sites are evaluated. It is expected that any changes in site permitting procedures will be published in early 2007. Some observers state that the overall problem is that the traditional FERC permitting approach stretches back almost 100 years and is no longer applicable to the emerging field of tidal and wave energy development. These issues are being reviewed by the Ocean Renewable Energy Coalition as well as many interested commercial interests in the emerging tidal and wave industry. The chart below provides a view of jurisdictional areas with impacts on tidal and wave energy development.

4.3 Additional Federal Oversight [9]

Federal Power Act, 16 U.S.C. § 817 (1) - FERC Authority and Jurisdiction

The Federal Energy Regulatory Commission (FERC) statutory authority states "it shall be unlawful for any person…for the purpose of developing electric power, to construct, operate or maintain any dam, …reservoir or powerhouse or other works across navigable waters of the United States….except in accordance with a license …[issued by FERC]. FERC has also determined that a wave energy project is a hydro project with a "power house" over which it has jurisdiction. Likewise FERC has jurisdiction over tidal and ocean current power projects up to three miles off shore. In 2005, FERC created the "Verdant exemption" which allows developers to deploy wave and tidal projects on an experimental basis, for a limited time frame (the initial exemption was for 18 months) provided that developers do not impact commerce by selling power to the grid and deploy projects to gather data for licensing. FERC must also give "equal consideration" to environmental and energy concerns (Sec. 4(e) of FPA, 16 U.S.C.§ 797) and be "best adapted to a comprehensive plan for developing a waterway, for protecting fish and wildlife and for other beneficial uses such as recreation, irrigation, water supply "(Sec 10 (a) FPA, 16 U.S.C. § 803 a).

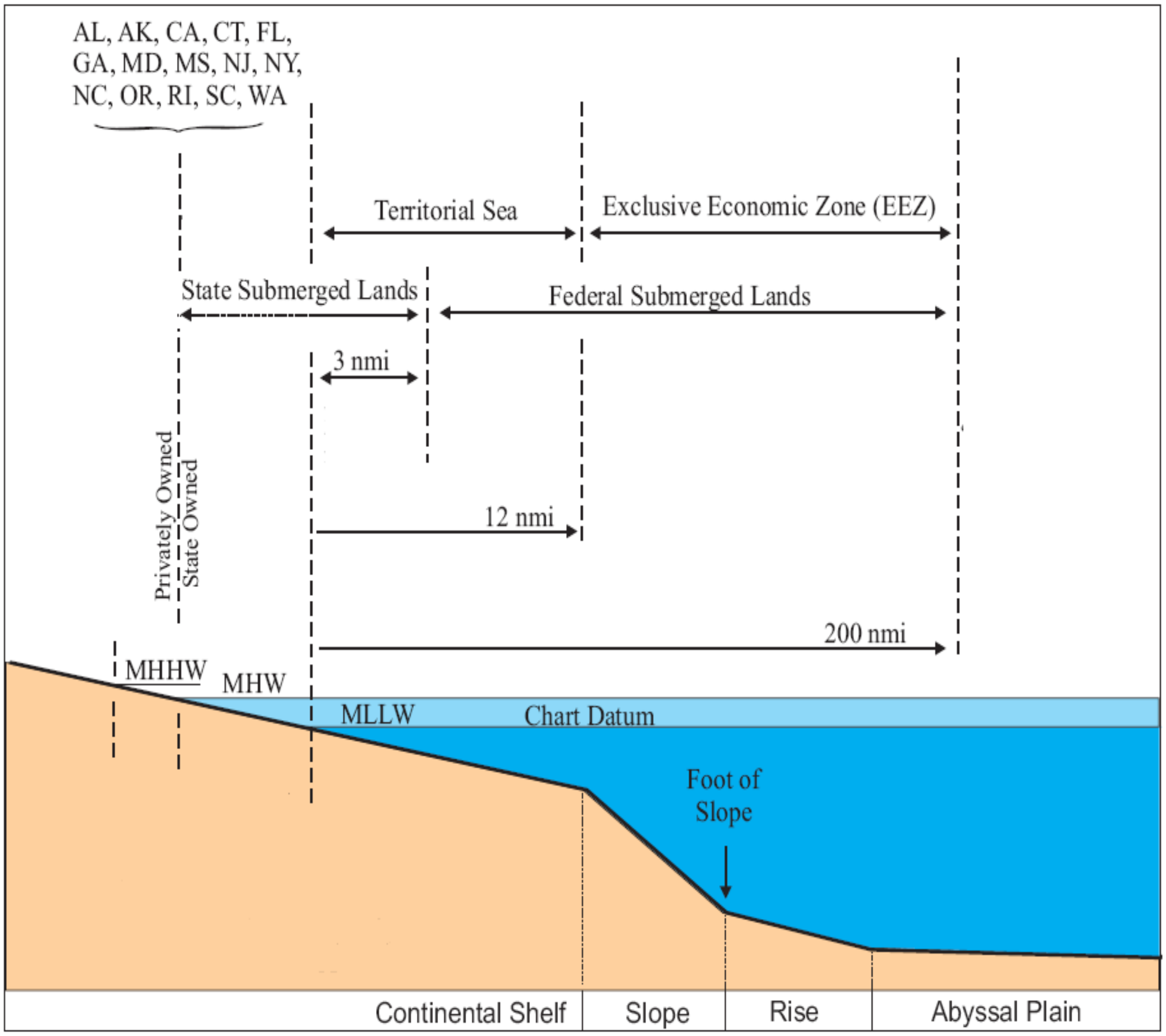


Figure 4.1 - Border Definitions of Submerged Lands Act of 1953 (MMS)

U.S. Army Corps of Engineers

Section 10 of the Rivers and Harbors Act of 1899 - 33 U.S.C. 403

Section 10 states that the creation of any obstruction not affirmatively authorized by Congress, to the navigable capacity of any of the waters of the United States is prohibited; and it is unlawful to build or commence the building of any wharf, pier, dolphin, boom, weir, breakwater, bulkhead, jetty, or other structures in any port, roadstead, haven, harbor, canal, navigable river, or other water of the United States, outside established harbor lines, except on plans recommended by the Chief of Engineers.

Also, it is unlawful to excavate or fill, or in any manner to alter or modify the course, location, condition, or capacity of, any port, roadstead, haven, harbor, canal, lake, harbor of refuge, or enclosure within the limits of any breakwater, or of the channel of any navigable water of the United States, unless the work has been recommended by the Chief of Engineers.

33 U.S.C. § 404 – Dredge and Fill Permit

A 404 permit (Section 404 "dredge and fill) permit from the Corps of Army Engineers may be required for FERC projects, but is only applicable up to the three (3) mile offshore limit. Structures that impact and are sited within navigable waterways are clearly the jurisdiction of the ACE. Projects involving such development must be reviewed by the ACE and permitted prior to installation as established by the Rivers and Harbors Act of 1890 and 1899.

US Coast Guard (USCG) Regulations

33 C.F.R. Part 62, 64, 66 Marine Navigation Lights

These regulations require and specify navigation lights must be posted on pilot, demonstration and commercial wave and tidal projects that may impact marine navigation and require that they be visible for one mile. The USCG would make a determination of requirements regarding the markings, lights and fog signals that would be appropriate for a given system deployment.

National Environmental Policy Act (NEPA)

42 U.S.C. § 4332 (c) Environmental Impact Statement

NEPA requires preparation of an Environmental Impact Statement (EIS) for "major federal actions significantly affecting the quality of the human environment." An environmental assessment (EA) must be prepared to determine if an EIS is necessary. Both the EA and the EIS must consider alternatives (build, no build, alternate location) and a variety of socio-economic, environmental and cultural impacts. The Federal Power

Act allows licensees to retain "third party contractors" on agency's approved list to prepare the EA or the EIS.

Coastal Zone Management Act – (CZM)

16 U.S.C. § 1374 – CZM Consistency Finding

Coastal States with approved CZM plans must issue a "consistency finding" that confirms that the proposed project is consistent with the state's CZM Plan. The Secretary of Commerce can consider whether to overrule the state's inconsistency finding if the applicant seeks review. The FERC license will not be issued without a consistency finding. **Coastal Zone Management Act (CZMA) of 1972** will involve three additional agencies that include (1) US Fish and Wildlife Service – US FWS, (2) National Oceanic and Atmospheric Administration – NOAA, and (3) National Marine Fisheries - NMF

National Historic Preservation Act

16 U.S.C. § 470 Protection of Historic Resources

If it is determined that there is a possible impact on historic resources, an evaluation of the project's potential impact on these resources must be completed in consultation with the state historic preservation agencies.

Fish and Wildlife Coordination Act

16 U.S.C. § 661 Fish and Wildlife Impacts

This act requires consultation with federal and state fish and wildlife agencies where a federal project impacts a body of water. FERC has its own independent consultation requirements under Section 10 (I) of the Federal Power Act.

Endangered Species Act (ESA)

16 U.S.C. § 1531 Endangered Species Impact

Section 7 of the ESA requires consultation with the Secretary of the Interior prior to project development to determine if endangered species may be present or adversely impacted by the project development.

Marine Mammals Protection Act

16 U.S.C. § 1361 – 1407 Harassment of Endangered Mammals

This federal law prohibits the harassment, hunting or capture of depleted endangered marine mammals. The project must prove that it does not "harass" protected marine mammals.

Submerged Land Act

43 U.S.C. § 1301 – Lease for Use of State Lands

The application of this law depends on the project location. At a minimum, the land lease would be required for transmission lines to shore. Also, under the FPA, 16 U.S.C. § 814, licensee has the power of eminent domain which could possibly be used to acquire state lands. It should also be noted that eminent domain authority has never been tested for in such an application.

Production Tax Credits

Section 45 IRS Code Renewable Energy Production Incentive (REPI)

The REPI would apply for tidal and wave energy projects and is structured such that municipal entities may receive cash reimbursements from the federal government for capital projects which include production of power from renewable energy sources.

4.4 FERC Permits for Wave Power Facilities

Nationwide, there are Preliminary FERC Permits in the process of development for six (6) planned or currently operational wave energy sites which include locations near Reedsport, Oregon; Newport, Oregon; the Makah Indian Nation in the state of Washington; San Francisco, California; Kaneohe, (Oahu) Hawaii; and Point Judith, Rhode Island. The single East Coast site in Rhode Island is in the planning stages.

With regards to the US Wave Energy Conversion (WEC) license history, Ocean Power Technology (OPT) has received a license and FONSI (Finding Of No Significant Impact) from the Navy for areas close to a naval base in Hawaii. In addition, AquaEnergy has been in the FERC process for over 4 years at its Makah Bay (Washington State) site. In late 2005, Green*Wave* (Energetech America) received a ruling asserting jurisdiction from FERC and is reconsidering the project.

4.5 Marine Ecology and Environmental Concerns

An overview of environmental impacts of Tidal and Wave Energy technologies can be assessed in general terms, however the required Environmental Impact Studies (EIS) will be site specific and will require time and detail to complete. The overall areas of possible concern are set forth in this section with the understanding that the actual EIS will be the product of many points of view and involve input from a range of agencies and inputs.

Physical Impacts. Physical factors involve exactly how a specific technology affects the water flow, the exact speed of the system rotation or movement and what species of fish, marine mammals and other marine organisms may be affected by its operation. Impacts on fish due to the direct strikes of turbine blades, as well as pressure, and shear or turbulence effects may be key elements of common concern for both tidal and wave systems.

These physical factors of system operation may also impact the sediment, and relate to the sediment size and composition. There may be concerns over the disturbance of benthic or life dwelling on the sea bottom due to cable installation to bring electricity to where it is needed. Changes in sediment transport and suspended loads may all require review and evaluation during pilot stage system operations and monitoring.

Impacts on marine vegetation which provides food and habitat for fish and other organisms near the system deployment may require study or evaluation. System operation may impact contaminants in the sediment that might be exposed by the action of the facility, and need to be considered.

Chemical factors in the water column may result in temperature impacts. While conventional hydropower projects can have a significant impact on temperature, this may not be as big an issue for tidal and wave technologies. Such issues as dissolved oxygen, nitrogen super saturation, and the role of dissolved solids may require evaluation. Extraction of energy may cause suspended solids to drop out, thereby changing turbidity.

Biological Factors need careful assessment including potential impacts on habitat for resident fish, plants and other types of organisms. Tidal currents may also serve as highways for movements of organisms. This includes constant, passive drift of aquatic invertebrates and seasonal drift of fish eggs and larvae. Other organisms that may be affected by the presence of hydrokinetic turbines in the waterway include reptiles, diving birds, and mammals.

Competing uses of natural streams may also be a factor in proposed environmental analysis and impact studies. Other uses of natural streams also need to be taken into account (e.g., the less visible a technology is, possibly the more hazardous from a navigation perspective). These issues may include recreational and commercial navigation, swimming and shoreline recreation, industrial discharges and withdrawals, aesthetics (visual and noise) and commercial fishing.

Species Inventory. An overall inventory of species within critical deployment zones for fish and marine mammals needs to be made for any project. **Seasonal Occurrence.** An evaluation of seasonal migrations that might impact turbine deployment has been proposed by the New York State Department of Environmental Conservation.

Threatened and Endangered Species. The potential impact to Threatened & Endangered species must be cited.

Noise Impacts. Potential noise impacts will need to be assessed.

Bio-Fouling Issues. Potential issues with respect to bio-fouling will need to be addressed. Other issues may require some preliminary deployment to begin to evaluate;

- Potential hazards of debris strike,
- Fish being attracted to the structure
- Cabling impacts on the seabed;
- Boating safety (recreational and commercial).

4.6 Transmission Issues[9]

The Long Island Power Authority owns 1,307 miles of transmission and sub-transmission lines that deliver power to 175 substations in its electric system. From these substations, 13,089 primary circuit miles distribute the power to 1.1 million customers in Nassau and Suffolk counties, and the Rockaway Peninsula in Queens County. In addition, LIPA has five transmission interconnections to neighboring electric systems and a new High Voltage Direct Current (HVDC) interconnection. It is our understanding that there are approximately 20 significant tidal power resource areas throughout the LIPA System that could feed the power grid. Any significant project that may be tied into the LIPA grid will require significant detailed study and measurement.

4.7 Marine Navigation Issues

Navigational issues include consideration of shipping lanes and United States Coast Guard (USCG) requirements to identify structures and warn of hazards that may obstruct or interfere in any way with shipping near tidal or wave power structures. These warning devices include warning lights, sound devices, and buoys that will indicate presence of these ocean power stations to mariners.

Some proposed technologies are completely submerged, others are partly submerged and some, such as most wave energy systems are largely operative at the water surface. Navigational issues are thus related to both site specific and technology specific needs and requirements based on the configuration of each system and the nature of its deployment. These specific requirements must therefore be presented on a case by case basis to the USCG for review and approval. Public review will also be required such that overall design and warning systems will be evaluated by commercial fishing and recreational boating interests.

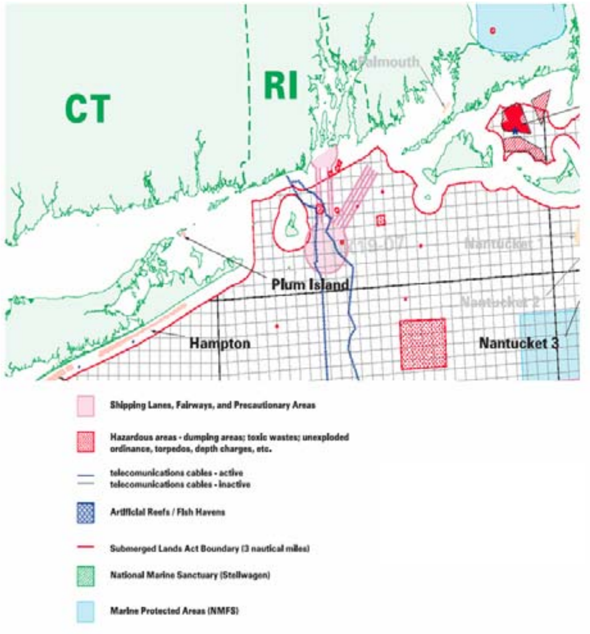


Figure 4.2 – Overview of Marine Navigational Issues

5. Conclusions and Recommendations

1. Ocean resources cover two-thirds of the earth's surface, representing a potentially huge, clean energy source. It is estimated that if less than 0.1% of the renewable energy within the oceans could be converted into electricity, it would satisfy the present world demand for energy more than five times over.[2]

2. Of six potential innovative marine energy or run of river systems, two such technologies are analyzed in this report, including:
   - Tidal In-Stream Energy Conversion (TISEC) and
   - Wave Energy Conversion (WEC).

   Such potential systems not evaluated in this study include:
   - Ocean Energy Technology,
   - River Based In-Stream Hydroelectric Technology,
   - Ocean Thermal Energy Conversion (OTEC), and
   - Tidal Barrage Systems.

3. Tidal power offers a promising future. Factors that support this view include:
   - Large off shore and near shore areas with energy production potential,
   - High level of predictability and repeatability of tidal processes, and
   - Significant interfaces between key tidal flows and utility grid connections.

4. A total of 485 potential tidal power sites were evaluated in Long Island offshore regional waters using the National Oceanic and Atmospheric Administration (NOAA) database of tidal currents speeds. Of these sites a total of twenty (20) locations of highest tidal flow speed were selected as most likely to be developed due to the combined factors of high speed of water flow and proximity to potential power grid interconnections. Of the total twenty sites, exactly half or 50% (10 sites) were identified in water depths of less than 50 feet (15.24m) and

50% (10 sites) were identified with water depths greater than 50 ft (15.24 m). Depth factors may influence many deployment factors including choice of TISEC technology, navigational issues, deployment method and overall power output[4]

5. Of the top twenty potential tidal power sites, four (4) sites have maximum water speeds in excess of 6 knots (3 m/sec), with a maximum water speed found near Little Gull Island in the Race at the eastern end of Long Island. None of the twenty selected sites had current velocities less than 4 knots or (2 m/sec). These water speeds present an effective operational dynamic range for eight (8) known TISEC technologies for power generation.

6. With more detailed study supported by actual field measurements of these promising sites, a more accurate overall evaluation of total potential power output from optimally deployed systems can be developed. Based on generalized information presented here from NOAA data base resources, it is estimated that using just a small fraction of the power in key cross sections of a few tidal flow areas would generate approximately 500 MW of TISEC power with 400 MW coming from The Race and 100 MW from inlets and bay areas. An economic analysis based on EPRI methodology referenced in this report (page 56) estimates one billion dollars[10] for construction with a production cost of 6.1 cents per kWh.

7. Potential Wave energy sites were evaluated for areas off eastern Long Island using US Army Corps of Engineers Wave Information Study (WIS) data and sites. These sites are representative of data for the entire Long Island region. For the approximately ten (10) WIS sites along the southern shore of Long Island, the average wave energy flux varied from 7 to 11 kW/m of wave front. A comprehensive study performed by Dr. A Grilli at the University of Rhode Island (URI) indicated WIS site # 83 off the eastern end of Long Island to have a wave energy flux value of 5.78 kW/meter of wave front. This compares with a Hagerman study that indicated a value of 9 kW/m and a Giannotti value of 10.56 kW/m (equivalent to 17 MW per mile)[6,7]

8. The key point is that the available energy out of a wave energy system given that the energy in the ocean (in kW/m of wave front) must consider (1) the amplitude, wave period and wave direction variables and (2) the measured efficiency of the system including the mechanical and electrical conversion to usable electric power. These factors reduce the overall power output to about 20% of the power in the wave. For these reasons, most wave power technology companies will not deploy a system if the wave energy flux is less than 25 to 30 kW/m. Hence, Long Island provides a poor to borderline opportunity for wave energy development on a utility scale application, based discussions of economic analysis with current leading wave energy systems.

9. Approximately 15 federal, state and local resource agencies have been identified to date that have some oversight on TISEC and WEC deployments in Long Island waterways. A key lead agency in the permitting process is the Federal Energy Regulatory Commission (FERC). Current regulations enable a potential wave or tidal power developer to apply for an exclusive right to file for a long term license for an ocean energy site after up to six years of review during which public and agency comments and concerns may be raised and answered.

10. An environmental impact statement would require a very through and complete examination of critical issues such as impacts on fish, marine mammals and other forms of wildlife. Issues relating to potential impacts on marine navigation and power line interconnections will also require critical review from resource agencies as well as the general public and will be performed on a site specific basis.

Calculation of Estimated Power Output from The Race and Offshore Inlets

1. This calculation is an estimate based on power outputs from two representative Tidal In-Stream Energy Conversion (TISEC) systems which includes (1) field testing of the Gorlov Helical Turbines, (GHT- Dr. Alexander Gorlov) and (2) technical understanding of an Orthogonal Tidal Turbine (Natural Currents –Dr. Victor Lyatkher).

2. The accepted equation for power generation from a TISEC - GHT[11] is based on an understanding of Bernoulli's Equation[11] with respect to the in-stream velocity component, as follows:

    a. $P\ (kW) = 0.5*\eta*\rho*A*v^3$
       η = mechanical turbine efficiency (%/100)
       ρ = density of seawater (kg/m^3)
       A = area of turbine cross-section (m^2)
       v = water current velocity (m/sec.)
    b. For a turbine efficiency of 35%, operating in a 3 m/sec. current (6 knots), the energy conversion would be 4 kW for the turbine cross section (the cross section is approximately 2.5 m^2) or approximately 1.6 kW per m^2 .

3. This compares favorably with a similar analysis performed by Dr. Victor Lyatkher[12], however the Lyatkher turbine claims an efficiency of about double 80% or (0.80). The Lyatkher turbine output and would therefore extract about 3.2 kW per m^2 in a flow with a water speed of 3 m-sec or 6 knots.

4. The cross sectional area of a proposed tidal power development of The Race[13] is based on a potential area for development that is 20 miles (32 km) by 12 miles (~20 km) with an estimated average water depth of 60 feet or about 20 m.

5. The overall estimate of potential power production is based on a conservative estimate of 1 kW of extractable power per square meter of cross section of water flow over the area described above (4). It is estimated that three (3) lines of turbines could be potentially installed per km across each 32 km cross section. This represents of total extractable power potential of 38,400 MW. Using approximately 1.3% of this cross section (at the most suitable locations within the total water flow) would enable 500 MW of power production, given this conservative estimate of extractable power (using 1 km per square meter of cross section versus 1.6 or 3.2 as presented above). Based on a comparison of cross sectional areas for the 19 inlet sites referenced in Section 2.1 of this report Potential Tidal Power Sites, with the data reviewed for The Race, it is estimated that approximately 100 MW could be extracted from these water ways using a very small fraction of the total cross sectional area.

6. More detailed and site specific information must be collected in order to make a truly accurate assessment of the power potential of these waterways, however, based on the assumptions and calculations above, the estimates of 500 MW potential of Tidal Power in The Race and 100 MW potential in the Inlet area are viewed as not only realistic but possible with sufficient investment.

Estimated Costs Per kWh for Tidal Power Generation

The estimate below of the Cost of Electricity (COE) is based on the EPRI methodology described in Appendix B of EPRI Report TP-002 NA (Berdard, Roger et al., *North American Tidal In-Stream Energy Conversion Technology Feasibility Study: Report TP-002 NA, Revision 2,* EPRI, June 10, 2006):

TPI = Total Plant Investment
FCR = Fixed Charge Rate (percent)
O&M = Annual Operating and Maintenance Cost
AEP = Annual Energy Production at Busbar (actually delivered to the local grid)

Assumptions:

- Total tidal power generation capacity: 400 MW
- Average capacity factor of overall tidal installation: 30%
- Long Island Power Authority will be considered a Municipal Utility Generator or "MG" described in the EPRI report
- Values calculated in 2004 constant dollars
- Production incentive of 1.5 cents per kWh (1993 dollars indexed to inflation)
- 100% financed by debt bonds
- No taxes
- Plant Life = 20 years
- Debt Financing Rate = 4.1%
- Inflation Rate = 3%
- Renewable Energy Production Credit = 1.73 cents/kWh for first ten years
- Renewable Energy Credit = 2.5 cents/kWh
- TPI = $1 billion
- FCR = 2.91% (real, inflation-adjusted)
- O&M = $35 million
- AEP = 1,051,200 MWh = 1,051,200,000 kWh

*COE = [(TPI*FCR) + (O&M)]/AEP*

COE = [(1000m*0.0291) + (35m)]/(1,051,200,000 kWh)
= $0.06098/kWh ≈ **6.1 cents/kWh**

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